ENVIRONMENTAL AFFAIRS

PCS Mining

A subsidiary of the Potash Corporation of Saskatchewan

PCS Mining File No.

INVESTIGATION OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF POTASH TAILINGS IN SASKATCHEWAN

by
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POTASH CORPORATION OF SASKATCHEWAN MINING LIMITED
ENGINEERING DEPARTMENT
ENVIRONMENTAL AFFAIRS SECTION
Saskatoon, Saskatchewan
Canada

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INVESTIGATION OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF POTASH TAILINGS IN SASKATCHEWAN

REPORT BY
Potash Corporation of Saskatchewan Mining Limited
Engineering Department
Environmental Affairs Section

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

INTRODUCTION

Potash ore in Saskatchewan consists of potassium chloride (KCl), sodium chloride (NaCl) and insolubles (clay and sand). About 60% of the ore is waste (NaCl and insolubles) and after being separated from the KCl is slurried and pumped to a tails pile. Current procedures deposit the tails on the top of the tails pile permitting the slurry to flow downslope. Heavier particles are deposited near the top of the slope and lighter particles precipitate near the toe and in a diked pond. Brine is pumped from the pond to re-slurry the tails.

There are currently ten producing potash mines in Saskatchewan storing in excess of 150 M tonnes of potash wastes on surface in tails piles from 20 to 60 m in height. Effective containment of these wastes requires a knowledge of the engineering properties of the wastes, however, to date the behavior of potash tailings has been poorly documented. In order to ensure the integrity of the waste management scheme, large scale failure of the tails piles must not occur and a knowledge of the engineering properties of the waste tails is essential to any analysis of the stability of both existing and proposed tails piles.

In order to make informed waste management decisions, an understanding of the influence of insoluble slimes on the tailings strength is necessary. The effects on stability of the tails pile when slimes occur as a stratified layer within the tails pile must be assessed. If separate storage of the slimes is considered the properties of the slimes must be identified. Since slimes would be stored outside the change in slimes strength resulting from leaching out of salt must be considered.

This program was therefore designed to provide some baseline data on the engineering properties of the salt tails and slimes, both separately and in combination. In order to asses the basic properties, the scope of work was designed to exclude a number of variables effecting salt tails, such as visco-plastic creep and time dependent characteristics.

METHODOLOGY

In order to include slimes variability between mines and ore bodies, samples of potash tails were collected from PCS Mining, Cory Division and PCS Mining, Rocanville Division.

A laboratory testing program was conducted by Golder Associates (Western Canada) Ltd. The samples tested consisted of salt tails (NaCl), salt free insolubles and various combinations of the two. The laboratory program included classification testing, permeability and consolidation testing and measurements of shear strength.

DISCUSSION

The salt tails were confirmed to consist primarily of NaCl with minor amounts of KCl. Mineralogical analyses of the insolubles indicated that the primary constituents are dolomite, quartz, potassium feldspar, anhydrite and clay (illite, chlorite, and septechlorite).

The grain size distribution of the salt crystals is similar to coarse grained salt while the insolubles contain silt and clay sizes. The insolubles classify as medium to highly plastic.

The salt tails classify as free draining materials with a coefficient of permeability in the order of 10^{-1} to 10^{-2} cm/sec. (The effects of plastic creep on long term porosity and permeability was beyond the scope of this study.) The salt free insolubles classify as very impervious with permeabilities in the order of 10^{-6} to 10^{-8}. The addition of insolubles to salt tails results in a significant reduction of the permeability. The poor drainage characteristics of the insolubles will have a significant implication on the stability of the tails piles. High pore pressures resulting from rapid loading will not dissipate rapidly and drainage paths within the tails pile will be affected by slimes layers.

The materials all exhibit reasonably high shear strength parameters. The effective angle of internal friction of the insolubles is approximately 30°, comparing favorably with the glacial materials in the foundation. Salt tails have an effective angle of internal friction of approximately 40°, approximating a coarse sand. The Mohr-Coulomb failure envelope for the salt tails is curved at low stresses and a straight line approximation could result in an over-estimate of stability. The addition of up to 20% insolubles to salt tails improves the strength available, yielding the highest shear strength parameters.

It is concluded that the salt tails are a high strength material, however, further investigation of factors effecting strength is required, The addition of slimes in a homogeneous mix will improve pile stability, however, slimes occurring as layers in the tails pile will reduce overall stability. High pore pressures can be generated in the insolubles or insoluble rich tails and these can be slow to dissipate. Leaching of salt from slimes will reduce the available strength.

The study was, of necessity, limited in scope, however, it has provided base line data to further the state-of-the art knowledge of the physical properties of potash tailings. It provides a logical basis for further efforts to be optimized

SOMMAIRE

INTRODUCTION

Le minerai de potasse de Saskatchewan est constitué principalement de chlorure de potassium (KCl), de chlorure de sodium (NaCl), et de minéraux insolubles (argile et sable). Après la récupération du KCl, les résidus, représentant environ 60% du minerai, sont mis en boue et pompés sur les piles de rejets. Selon les procédures actuelles, les résidus sont déversés sur le sommet des piles, permettant ainsi à la boue de s'écouler. Les particules les plus lourdes précipitent près du sommet, tandis que les particules les plus légères se déposent au pied de la pente et dans un bassin endigué. La saumure du bassin est pompée et ré-utilisée pour la disposition des résidus.

Présentement, 10 mines de potasse sont opérationnelles en Saskatchewan, et plus de 150 millions de tonnes métriques de résidus sont entassées sous forme de piles de rejets. Une connaissance des caractéristiques physiques et chimiques des résidus est nécessaire pour accomplir des analyses de stabilité, afin d'éviter des ruptures majeures des piles de rejets existantes et futures. Une connaissance approfondie des propriétés physiques et chimiques est donc primordiale afin d'assurer une gestion judicieuse des résidus, ainsi qu'un confinement efficace et sécuritaire. Malheureusement, la documentation pertinente au comportement des résidus de potasse a été négligée.

L'influence des vases de minéraux insolubles sur la résistance et la capacité portante des piles de rejets doit être connue et comprise afin de pouvoir prendre des décisions adéquates. Les effets des couches de vases stratifiées, sur la stabilité des piles de rejets doivent être évalués. Si l'entreposage séparé des vases et des résidus de sel est considéré, les caractéristiques physiques et chimiques des vases doivent également être identifiées. Étant donné que ces vases doivent être entreposées à l'extérieur, les changements de résistance provenant de la lixiviation du sel doivent aussi être considérés.

Par conséquent, ce programme d'étude a été conçu de façon à pouvoir fournir l'information de base sur les résidus de sel et les vases, séparement et conjointement. Afin d'évaluer les propriétés de base un certain nombre de variables, comme le fluage visco-plastique et les caractéristiques variant avec le temps, ont été excluses.

MÉTHODOLOGIE

Des échantillons de résidus de potasse de PCS Mining, Cory Division et de PCS Mining, Rocanville Division ont été collectés, afin d'inclure la variabilité des vases d'une mine à l'autre.

Un programme d'analyse en laboratoire a été dirigé par Golder Associates (Western Canada) Ltd. Les échantillons analysés étaient formés de résidus de sel (NaCl), de minéraux insolubles, et de diverses combinaisons des deux. Ce programme comprenait des analyses granulométriques, de perméabilités, de consolidation et des mesures de contraintes de résistance au cisaillement.

DISCUSSIONS

Les analyses confirmaient que la composition des résidus de sel était principalement du NaCl avec des quantités minimes de KCl. L'analyse minéralogique des minéraux insolubles a indiqué qu'ils étaient principalement formés de dolomie, de quartz, de feldspath potassique, d'anhydrite et d'argile (illite, chlorite et septechlorite). La distribution granulométrique des cristaux de sel est similaire à celle d'un sel grossier, tandis que les grains des minéraux insolubles sont de la grosseur de ceux des silts et des argiles. Les minéraux insolubles sont considérés comme étant de moyennement à hautement plastiques.

Les résidus de sel, ayant des taux de perméabilité de l'ordre de 10^{-1} à 10^{-2} cm/sec, drainent librement (les effects du fluage plastique sur la porosité et la perméabilité à long terme sont au-delà de l'envergure de cette étude et n'ont pas été considerés).

Les minéraux insolubles sont très imperméables. Ils ont des taux de perméabilité de l'ordre de 10^{-6} à 10^{-8} cm/sec. Les hautes pressions capillaires crées par un chargement subit ne se dissipent pas rapidement. Le taux de drainage des piles de résidus est affecté par la présence des couches de vases.

Tous les matériaux démontrent des paramètres de résistance aux cisaillement assez élevés. L'angle de friction interne des minéraux insolubles est d'environ 30°, se comparant favorablement aux matériaux glaciaires. Les résidus de sel ont un angle de friction interne d'environ 40°, similaire à un sable grossier.

L'enveloppe de rupture Mohr-Coulomb, des résidus de sel est curviligne sous basses contraintes, et une approximation linéaire pourrait surestimer la stabilité. L'addition de minéraux insolubles, jusqu'à environ 20%, aux résidus de sel améliore la résistance et la capacité portante, démontrant des paramètres de résistance aux cisaillement plus élevés.

Il a été conclu que les résidus de sel sont des matériaux de haute résistance, toute fois, des études plus approfondies sur les facteurs affectant cette résistance sont nécessaires. L'addition d'une mixture homogène de vases aux résidus de sel, améliorera la stabilité des piles de rejets, par contre des couches de vases stratifiées en réduira la stabilité. De hautes pressions capillaires peuvent être engendrées par les minéraux insolubles ou par des résidus de sel riches en minéraux insolubles. Ces pressions peuvent se dissiper très lentement. La lixiviation du sel dans les vases réduira la résistance et la capacité portante des résidus.

L'envergure de cette étude était passablement limitée mais elle a quand même permis d'établir une plus grande connaissance des propriétés physiques des résidus de potasse. Cette étude fournit une base logique pour les développements futurs.

INVESTIGATION
OF THE
PHYSICAL AND CHEMICAL CHARACTERISTICS
OF
POTASH TAILINGS IN SASKATCHEWAN

TECHNICAL REPORT

PCS Mining
Environmental Affairs

1.0 INTRODUCTION

1.1 General

Potash ore consists of potassium chloride, sodium chloride and clays and sands (insolubles). About 60% of the ore is waste which, after being separated from the potassium chloride (KCl), is slurried in brine and pumped to a waste disposal area.

There are currently ten producing potash mines in Saskatchewan (Figure 1.1). Since the first potash was produced in Saskatchewan in 1969, potash wastes have been stored on surface. In excess of 150 million tonnes of potash wastes are now stored in piles on surface and each of the ten mines has brine ponds ranging in size up to 200 hectares. To prevent contamination of the environment, the potash wastes stored on surface must be contained within a waste management area. Effective storage and containment requires a knowledge of the engineering properties of the waste products. The engineering properties and behavior of potash tailings have been poorly documented and further data and information is required to ensure effective waste management schemes can be implemented and maintained.

The purpose of this study was to obtain and document additional data on the physical and engineering properties of potash tailings and further our understanding of the behavior of the tailings within the waste management system.

1.2 Waste Products From Potash Beneficiation

The sylvinite ore mined in conventional Saskatchewan potash mines contains approximately 50% Halite (sodium chloride), 45% Sylvite (potassium chloride) and up to 5% water insoluble minerals (clays and sands). The water insoluble minerals occur primarily as thin stratigraphic layers interspersed throughout the ore body (Figure 1.2). These seams are variable by nature and thus the amount of insolubles present in the raw ore varies from mine to mine and to a lesser extent, at a specific minesite. In general, the potash beneficiation process involves separating the sylvite (KCl) and processing it to a marketable product while discharging the halite (NaCl) and water insolubles as waste products.

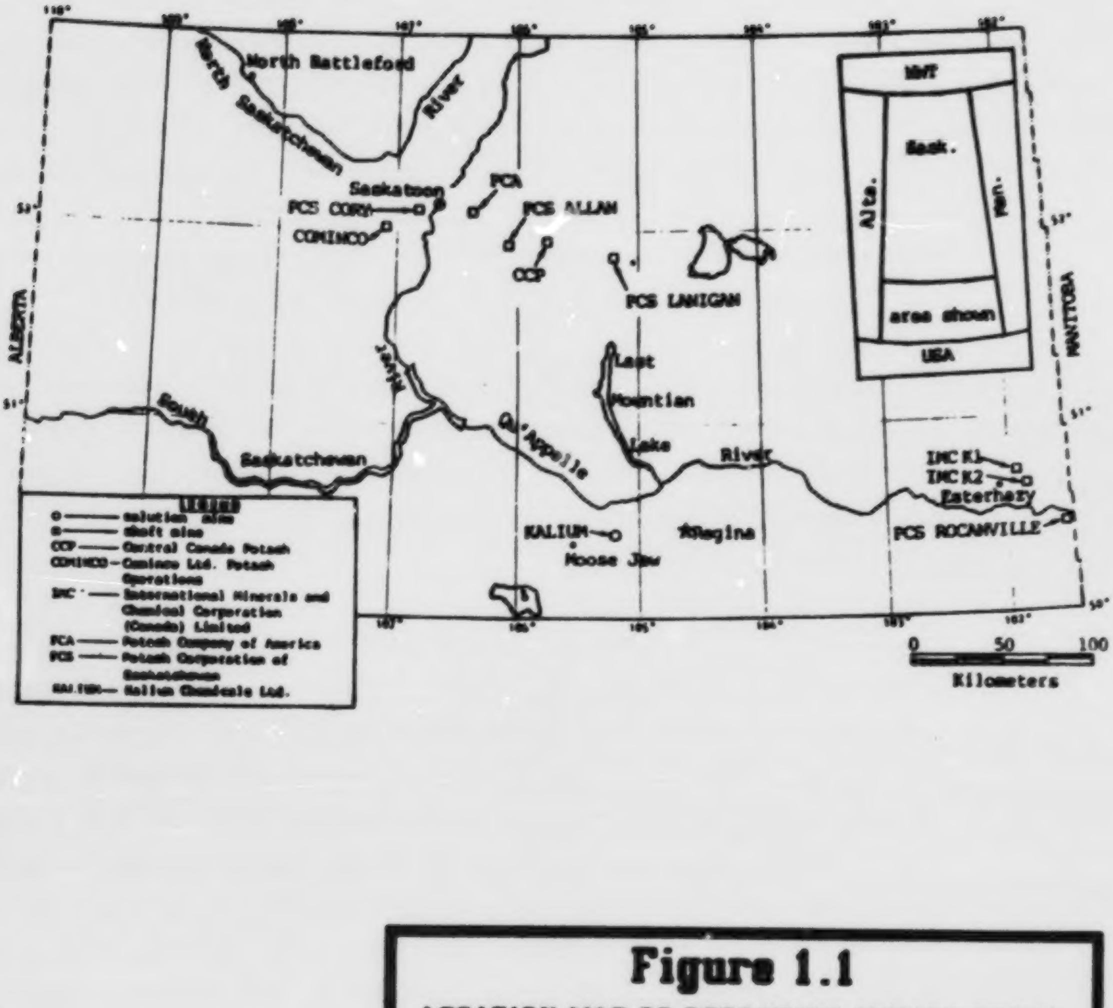

110°
109°
108°
107°
106°
105°
104°
103°
102°
North Battleford
North Saskatchewan River
Saskatoon
PCA
PCS CORY
PCS ALLAN
COMINCO
CCP
PCS LANIGAN
ALBERTA
MANITOBA
River
South Saskatchewan
Qu'Appelle
Last Mountian Lake
River
IMC K1
IMC K2
Esterhazy
PCS ROCANVILLE
KALIUM
Moose Jaw
Regina
52°
51°
50°
NWT
Sask.
Alta.
Man.
area shown
USA
0
50
100
Kilometers
LEGEND
solution mine
shaft mine
CCP — Central Canada Potash
COMINCO — Cominco Ltd. Potash Operations
IMC — International Minerals and Chemical Corporation (Canada) Limited
PCA — Potash Company of America
PCS — Potash Corporation of Saskatchewan
KALIUM — Kalium Chemicals Ltd.

Figure 1.1

LOCATION MAP OF PRODUCING POTASH MINES IN SASKATCHEWAN (1984)

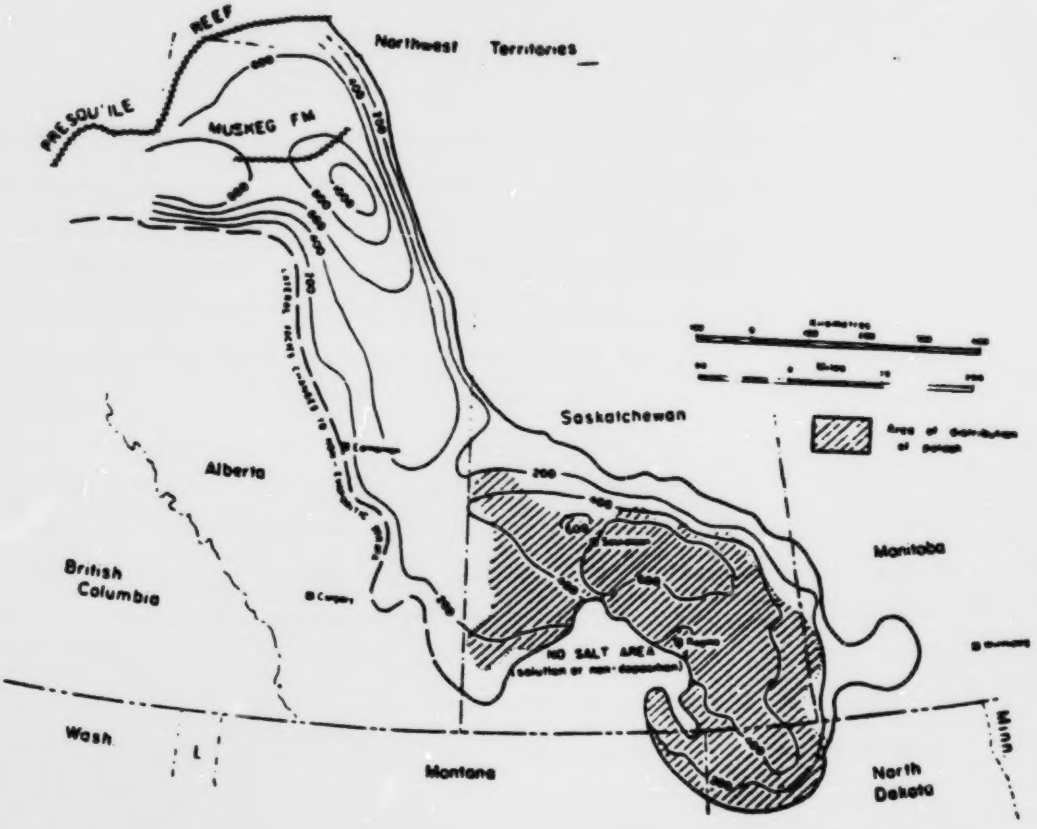

PRESQU'ILE
REEF
Northwest Territories
MUSKEG FM
200
400
Saskatchewan
Area of distribution of potash
Alberta
Manitoba
British Columbia
NO SALT AREA
(solution or non-deposition)
Wash.
L
Montana
North Dakota
Minn.

Figure 1.2

DISTRIBUTION OF PRAIRIE EVAPORITE BEDS IN SASKATCHEWAN (after Dunn, 1976)

The beneficiating process used in conventional mines involves several stages of separation (Figure 1.3). The ore is crushed and ground in brine saturated in KCl and NaCl. The insolubles are separated and removed by chemical and physical methods. Sylvite (KCl) is then separated from the halite (NaCl) in the deslimed ore by mechanical means. The saleable product, KCl, is then processed, sized and debrined. The NaCl which has been separated from the KCl is filtered and discharged as waste.

The water insolubles (waste) are purged from the system as underflow from the slimes thickener. Some of the re-circulating brine and halite (NaCl) are discharged along with water insolubles. The combined discharge, i.e. slimes, from the thickener underflow is of variable composition, and consists of 10 to 60% water insolubles along with 40 to 90% salt crystals (NaCl) slurried in a saturated brine solution.

The solid sodium chloride crystals which have been separated from the KCl in the beneficiating process are conventionally mixed with the underflow from the slimes thickener, slurried in brine and pumped by pipeline to the waste disposal area.

The slurried wastes are discharged onto the tails pile near its high point. As the slurry flows down the gradual slope of the tails pile, the solid particles are deposited. Presumably, the larger particles (NaCl crystals) are deposited near the top of the tails pile while the smaller insoluble particles are deposited near the toe. Control may be imposed on the flow by means of crude decant structures to precipitate as many of the insolubles as possible on the tails pile prior to releasing the brine into dyked ponds. Further precipitation is promoted in settlement ponds prior to pumping the brine back to the refinery to re-slurry the tails.

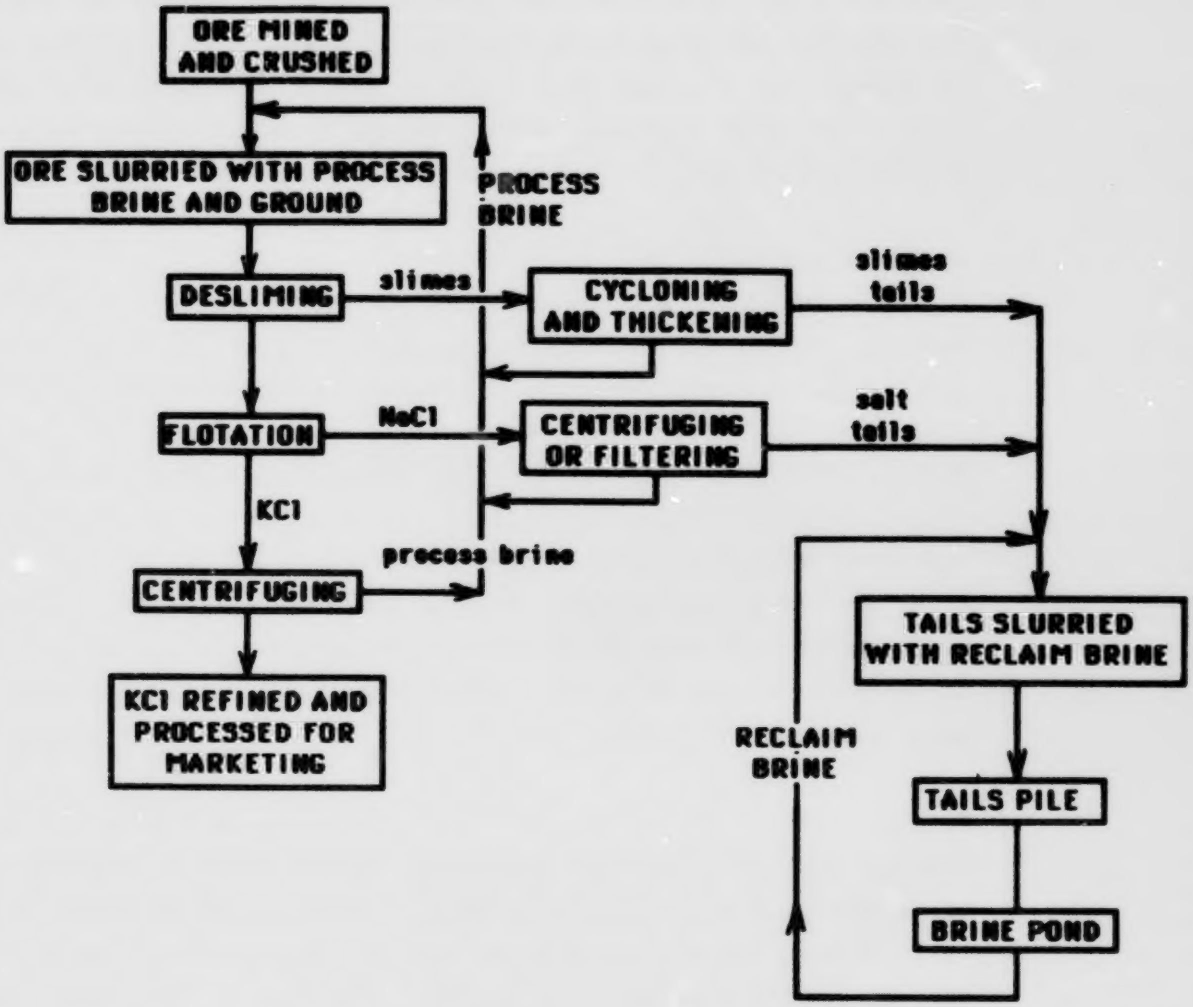

ORE MINED AND CRUSHED
ORE SLURRIED WITH PROCESS BRINE AND GROUND
PROCESS BRINE
DESLIMING
slimes
CYCLONING AND THICKENING
slimes tails
FLOTATION
NaCl
CENTRIFUGING OR FILTERING
salt tails
KCl
process brine
CENTRIFUGING
KCl REFINED AND PROCESSED FOR MARKETING
TAILS SLURRIED WITH RECLAIM BRINE
RECLAIM BRINE
TAILS PILE
BRINE POND

Figure 1.3

SIMPLIFIED SCHEMATIC OF POTASH REFINING PROCESS
CONVENTIONAL POTASH MINES
IN SASKATCHEWAN

The above deposition process results in a highly stratified tails pile with salt tails predominating near the spiggoting point and thicker layers of slimes occurring near the toe of the slope and in the settling ponds. Using this downslope method of deposition has resulted i the tails pile over running the accumulations of slimes and possibly resulting in the development of layers of insolubles in or beneath the tailings pile. The extent of the segregation and stratification within the existing tails pile is not clearly defined at this time however, it is believed to be extensive.

1.3 Study Purpose

In order to ensure the integrity of the waste management systems handling the potash tailings, large scale failure of the tailings must not be permitted to occur. Little is presently known about the likelihood of pile failure which could occur through foundation failure or due to internal slip surfaces. Due to the relatively high clay content of the insolubles, the occurrence of slimes layers within or beneath the tails pile could determine the failure criteria for the salt tailings. Thus, a knowledge of the distribution and engineering properties of the waste products in the tails pile is essential to analyzing the existing facilities and making factual waste management decisions.

Numerous options may be available to the industry in continued waste storage; such as increasing the height of the existing tails piles using wastes as presently discharged; physically separating the salt tailings and slimes for separate storage or select placement; or various combinations of these options. In order to make quantitative engineering decisions regarding waste management and solid waste storage options, the properties of the materials being handled must be understood. Of particular concern is definition of shear strength parameters which are required for all foundation and earthwork stability problems.

The purpose of this study was to conduct a preliminary testing program to study the baseline properties of the waste products, separately and in combination, to further our understanding of the material properties and their implications in waste management.

The overall objectives were identified in the research proposal, a copy of which is included as Appendix C.

1.4 Scope of Work

In general, the scope of work included:

- reviewing and cataloguing of existing published data on the physical characteristics of waste products generated by Saskatchewan potash mines.
- collecting representative samples of the potash wastes from selected mines owned by the Potash Corporation of Saskatchewan.
- conducting a laboratory testing program to provide data on the engineering properties of potash wastes.
- compiling the above data in a report.

Existing information on PCS Mining files indicated that ore extracted from the Esterhazy Member of the Prairie Evaporite Formation by PCS Mining Rocanville Division contained the lowest percentage of water insolubles while ore extracted from the Patience Lake Member of the Prairie Evaporite Formation by PCS Mining Cory Division contained the highest percentage of water insolubles. In addition, the insolubles found at Rocanville appeared to contain the lowest clay component while Cory was near the highest clay content.

These two mines were therefore selected as the source of samples to be analyzed in detail.

The testing program was designed as a broad program to provide a basic understanding of the material properties. Considering the lack of baseline data, the program was designed to provide a baseline rather than a detailed study of all parameters. Because of the various solid-waste storage options available to the industry, the materials were considered in isolation (salt tails only and insolubles only), and in combination (mixtures of salt tails and insolubles). This selection was also a reflection of the numerous stratigraphic possibilities which may be present in the existing waste piles.

2.0 EXISTING INFORMATION

2.1 Sources of Existing Information

Despite the fact that potash wastes have been handled and stored at potash mines in Saskatchewan for approximately fifteen years, extremely limited information has been published in relation to the properties of potash tailings. Limited publications are available on the composition of the ore body.

The primary source of data related to the engineering properties of potash wastes was limited to the research activities of the Potash Corporation of Saskatchewan Mining Limited.

2.2 Classification of Data

The search for existing data was concentrated in several specific areas, namely:

- Mineralogy of the clay marker seams in the ore bodies,
- Composition of slimes produced as waste product,
- Composition of salt tails produced as waste product,
- Physical properties of slimes and/or water insolubles,
- Physical properties of salt tailings.

2.3 Discussion

Appendix B presents a summary of specific references of relevance to the study. The scope and results of each reference study are discussed and summarized in Appendix B.

The mineralogy of the clay seams in the ore bodies was discussed by Dean (1971), Dean (1978) and Mossman et al (1982). The mineralogy of the clay seams was analyzed in qualitative terms by the above authors. The studies concluded that the main clay minerals present were illite, chlorite and septechlorite while non-clay water insoluble constituents included anhydrite, dolomite, quartz, hematite and potassium feldspar.

Arnold (1981) attempted to analyze the mineralogical composition of the water insoluble portion of slimes and salt tails at PCS Mining Cory Division. The analysis was reported in qualitative terms only.

In 1982, PCS Mining, Environmental Affairs Section obtained samples of slimes from all four operating divisions of PCS Mining and had quantitative analyses of the mineralogy of the insoluble portion conducted by the Saskatchewan Research Council (SRC) using x-ray diffraction techniques. This is the only comprehensive quantitative analysis available as input to this study. Detailed results of the SRC results are given in Appendix B. The analyses indicate similarities in the composition of insolubles from PCS Mining Cory, Allan and Lanigan Divisions, each with approximately 50% clay content. In contrast the samples from PCS Mining Rocanville Division are approximately one half the clay content, with approximately 25% of the total sample consisting of clay. Conversely the Rocanville samples contain a much higher percentage of dolomite and quartz.

The composition of the salt tailings at each minesite were also analyzed by PCS Mining, Environmental Affairs Section in 1982. Detailed analyses are included in Appendix B. As expected, the salt tails are primarily NaCl containing minor amounts of KCl and water insolubles. In the case of PCS Mining Rocanville Division, minor amounts of magnesium chloride are also present. This constituent is unique to the Rocanville ore body.

Limited classification testing on a slimes sample from PCS Mining Cory Division was performed by Bromwell Engineering in 1982. The tests consisted of Atterberg Limit determinations which indicated a material of medium plasticity. Under contract to PCS Mining, BBT Geotechnical Engineers Ltd (BBT) of Saskatoon conducted a series of tests on slimes sampled at each of the four operating divisions. These samples were duplicate samples to the ones analyzed by the SRC as discussed above. Details of the laboratory testing conducted by BBT are included in Appendix B. A number of the tests attempted failed to produce meaningful results when standard soil testing procedures were applied to the samples containing salt crystals. The tests conducted on only the insoluble portion of the slimes (salt free) indicate that they are of low to medium plasticity with the Cory and Allan samples exhibiting the highest plasticity (corresponding to highest clay content) and the Rocanville samples exhibiting the lowest plasticity (corresponding to lowest clay content). In general, the results of the laboratory tests on the salt free insolubles confirm the expected differences in physical properties corresponding to variations in clay content of the samples. In particular, index testing and moisture-density tests can be related to the clay content of the sample. The salt free samples exhibit index characteristics somewhere between what would be expected of illite and kaolinite.

In 1983, the University of Saskatchewan Geotechnical Group ran a limited series of tests on a slimes sample obtained at PCS Mining Lanigan Division. The sample consisted primarily of water insolubles in a saturated brine pore fluid (i.e. 100% passing the No. 200 sieve). This medium plastic material was tested in direct shear, with an indicated effective angles of internal friction of:

ϕ' peak 34°
ϕ' residual 28°

The most comprehensive testing program to determine the physical properties of salt tailings was conducted by the University of Saskatchewan Geotechnical Group (Pufahl and Yosheda, 1982). This study, sponsored by PCS Mining Research and Development, studied the properties of salt tailings generated at the PCS Mining Rocanville Division refinery. The salt tailings were studied to determine the feasibility of using them as mine backfill in a Total Extraction Mining technique. Summaries of their report are included in Appendix B. Bulk samples were obtained from the minesite and reconstituted in the University laboratory. An extensive series of classification, compaction, consolidation and strength testing was conducted to assess basic properties and the factors influencing them. The laboratory testing program identified a very unique and complex material exhibiting many of the characteristics of sand with the added complications of solubility and cementation. Many of the strength and deformation characteristics were found to be time dependent.

Additional strength testing (triaxial compression) was conducted by the University of Saskatchewan (Pufahl and Loi, 1984) on salt tailings sampled at the PCS Mining Rocanville Division refinery. The primary purpose of this program was to attempt to predict elastic parameters of the salt tailings.

Golder Associates (1977) attempted to measure the strength parameters (by direct shear) and permeability of the in-situ tailings at PCS Mining Cory Division. Limited success was achieved and a high degree of variability was noted in the tailings pile. The field investigation noted extensive segregation of materials. The strength testing suggested that the maximum shearing resistance of the salt tails was a non-linear function of applied normal stress.

Golder Associates (1983) conducted a field drilling program for PCS Mining at the Lanigan tails pile and samples were recovered from the existing tails pile for further analysis by the University of Saskatchewan. No results are yet available.

3.0 SAMPLING PROGRAM

3.1 Sample Sources

After review of existing information, PCS Mining Cory Division and PCS Mining Rocanville Division were selected as the source refineries for potash wastes to be analyzed in the study. These two sites are representative of the two ore bodies from which the PCS operating mines obtain raw ore. PCS Mining Cory Division is representative of the ore obtained from the Patience Lake Member of the Prairie Evaporite Formation and PCS Mining Rocanville Division is representative of the ore obtained from the Esterhazy Member of the Prairie Evaporite Formation.

The Cory site is representative of the highest water insoluble content in ore along with the highest clay content in the insolubles while the Rocanville site is representative of the lowest percentages of both.

3.2 Collection and Handling of Samples

Samples of slimes (solids consisting of salt crystals and insoluble particles) and simultaneous samples of salt tailings were obtained from the two minesites in April, 1984 by engineers from PCS Mining Environmental Affairs Section.

Samples were collected from PCS Mining Rocanville Division on April 26, 1984. All samples were collected from within the refinery prior to slurrying the waste for pumping to the tails pile. The samples of slimes were obtained directly from the slimes thickener discharge. Samples of salt tailings were obtained from the continuous discharge from the tails filter.

Samples were collected from PCS Mining Cory Division on April 27, 1984. All samples were collected from the within the refinery. Slimes samples were collected by intercepting the discharge line from the slimes thickener. Samples of salt tailings were removed from the system at a point immediately prior to slurrying the tails for pumping to the tails pile.

All samples were collected in 20 litre plastic containers and samples were completely saturated in brine within the containers. The containers were sealed with self-sealing plastic lids, leaving no air spaces within the container. Samples were transported in these containers and stored at controlled temperatures until testing.

Storing the samples in the above fashion prevented any significant cementation of the salt crystals during the storage period and when the containers were opened to remove samples for testing the appearance and consistency of the salt tailings was similar to the time of sampling.

Approximately twenty-five to thirty 20-liter pails of each material (slimes and salt tails) were collected at each minesite, resulting in over one hundred pails total.

4.0 STUDY METHODOLOGY

The overall study definition was directed toward establishing some basic material properties and gaining some insight into the variations in material properties resulting from various combinations of materials.

Following collection of the samples, the chemical and mineralogical composition of the materials was established. Based on the previous data, this would permit an assessment of whether the samples were consistent with the expected waste discharge at the mines and could be considered representative. This basic definition of sample constituents was also required as input to the analysis and interpretation of results.

Representative samples of slimes (mixture of salt tails and insolubles) and salt tails were selected for detailed analysis. Quantitative analyses of the insoluble mineral constituents were conducted by the Saskatchewan Research Council (SRC), using x-ray diffraction techniques. These analyses were conducted on the water insoluble portion of the slimes samples after removal of the salt crystals and brine. The results of these mineralogical analyses, as illustrated in Figure 4.1 and detailed in Tables 4.1 and 4.2, are consistent with previous analyses, showing dolomite, potassium feldspar, quartz, anhydrite and clay as the major components. The clay contents of the Cory and Rocanville samples were approximately 40% and 15 to 20% respectively, which is consistent with previous analyses.

Chemical analyses of representative samples of the salt tailings were performed by the PCS Mining chemical laboratories. The results of these analyses, as given in Table 4.3, indicate that NaCl forms the major constituent of the salt tailings with minor amounts of KCl and water insolubles. The Rocanville salt tailings contain minor amounts of $MgCl_2$, reflecting the composition of the ore body. The slightly lower NaCl component in the Rocanville samples is a logical reflection of the refining process at that mine.

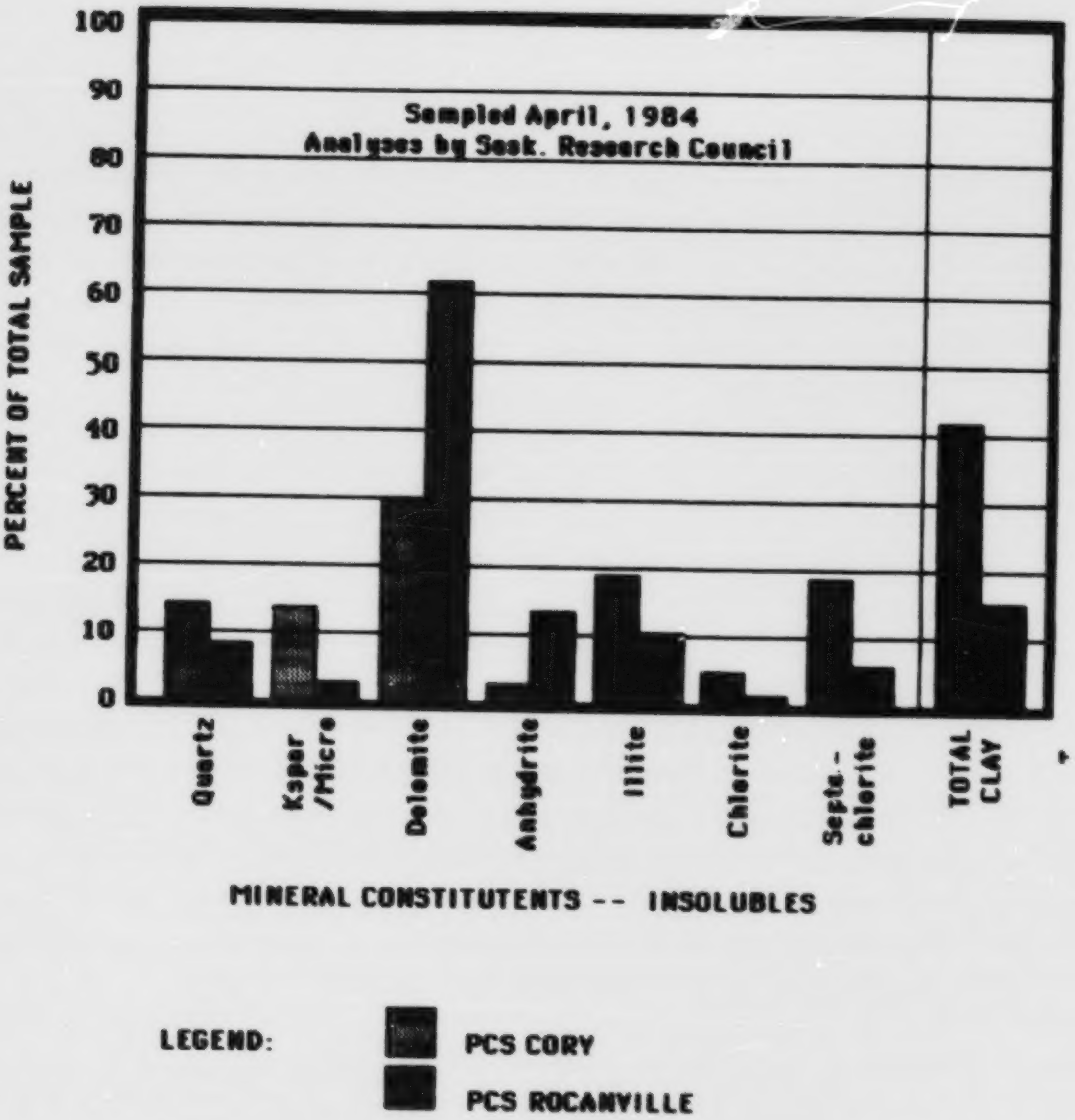


Figure 4.1

MINERALOGICAL COMPOSITION OF INSOLUBLES

Table 4.1
Mineralogical Analyses of Water Insoluble Tails
PCS Mining Rocanville Division Samples

MINERAL	PERCENT COMPOSITION			
	SAMPLE#1	SAMPLE#2	SAMPLE#3	SAMPLE#4
Quartz	10.2	7.9	7.5	8.4
KSpar/Micro	1.4	2.3	2.2	5.7
Plagioclase	0.0	0.0	0.0	0.0
Calcite	0.0	0.0	0.0	0.0
Dolomite	66.6	55.6	67.0	59.9
Siderite	0.0	0.0	0.0	0.0
Halite	0.0	0.0	0.0	0.0
Sylvite	0.0	0.0	0.0	0.0
Hematite	0.0	0.0	0.0	0.0
Gypsum	0.0	0.0	0.0	0.0
Anhydrite	0.0	15.9	9.8	13.1
Illite	12.5	11.8	7.8	6.1
Chlorite	2.5	0.0	0.0	0.0
Septechlorite	6.5	6.5	5.8	6.7
Montmorillonite	0.0	0.0	0.0	0.0
Mixed Layer Clay	0.0	0.0	0.0	0.0

Note: - All samples taken April 26,1984
- All analyses performed by the Saskatchewan Research Council

Table 4.2
Mineralogical Analyses of Water Insoluble Tails
PCS Mining Cory Division Samples

MINERAL	PERCENT COMPOSITION SAMPLE#1	SAMPLE#2	SAMPLE#3	SAMPLE#4
Quartz	15.9	12.6	14.8	12.9
KSpar/Micro	12.7	17.4	9.5	14.1
Plagioclase	0.0	0.0	0.0	0.0
Calcite	0.0	0.0	0.0	0.0
Dolomite	30.4	28.6	31.7	28.5
Siderite	0.0	0.0	0.0	0.0
Halite	0.0	0.0	0.0	0.0
Sylvite	0.0	0.0	0.0	0.0
Hematite	0.0	0.0	0.0	0.0
Gypsum	0.0	0.0	0.0	0.0
Anhydrite	0.0	0.0	0.0	3.1
Illite	17.5	19.0	20.8	18.2
Chlorite	5.4	5.5	4.7	4.8
Septachlorite	18.1	16.8	18.5	18.3
Montmorillonite	0.0	0.0	0.0	0.0
Mixed Layer Clay	0.0	0.0	0.0	0.0

Note: - All samples taken April 27,1984
- All analyses performed by the Saskatchewan Research Council

Table 4.3

Composition of Salt Tails Samples

CONSTITUTENT	ROCANVILLE SAMPLES #1	ROCANVILLE SAMPLES #2	CORY SAMPLES #1	CORY SAMPLES #2
KCl	2.51	2.82	0.27	0.45
NaCl	94.02	93.62	97.80	97.90
$MgCl_2$	2.63	2.46	0.0	0.0
Water Insolubles	0.34	0.34	1.51	1.45

Note: All samples consisted of solids less brine

All analyses performed by PCS Mining Analytical Laboratory

Based on the mineralogical analyses of the water insolubles and the chemical analyses of the salt tails, it was concluded that the samples obtained were representative of the tailings generated at the respective minesites and a detailed testing program was defined.

The detailed testing program was designed to provide basic data on the properties of the water insolubles and the salt tails, and data on the properties of the materials combined in various proportions as might be evidenced in the field tailings pile. Since the clay component tends to dominate the physical properties of material mixtures, the program was designed to evaluate the effects of increasing clay content on the material properties, starting at relatively low percentages.

Since little information has been published in this area, it was considered prudent to apply restrictions to the program and to strive for a baseline data bank on which more informed decisions could be made to delineate further detailed testing. Thus, the efforts of this program were directed to determining the possible changes in material properties resulting from adding slimes to salt tails under controlled conditions, i.e. holding as many variables constant as reasonably possible. Thus, evaluation of many factors which are known to effect many of the properties of salt tailings, such as time effects; cementation and initial density, was considered beyond the scope of this study and was recognized and evaluated in cursory fashion only. The incorporation of many of these factors would be a logical extension of this study.

The following sample approximate compositions were selected for detailed study:

1) 100% water insolubles — 0% salt (salt free)
2) 10% water insolubles — 90% salt
3) 20% water insolubles — 80% salt
4) 30-50% water insolubles — 50-70% salt
5) 0% water insolubles — 100% salt

Golder Associates (Western Canada) Ltd were selected by PCS Mining to provide the laboratory testing services for the study. All samples obtained from the minesites were delivered to the Golder Associates materials testing laboratory in Saskatoon. The testing program and methodology was specified by PCS Mining and the tests were conducted under the guidance of PCS Mining, Environmental Affairs.

Because of the salt component, standard soil testing methods were not applicable to many of the tests and alterations were made in the testing procedures to accommodate the salt environment. Standard ASTM methods as defined in the Annual Book of ASTM Standards, Section 4, Volume 4.08, published in 1984, were followed where possible with innovation and modifications to equipment and procedures as required to accommodate the unique properties of salt crystals and dissolved salt.

The materials were initially classified for engineering purposes by defining the following characteristics:

- specific gravity
- grain size distribution
- Atterberg Limits.

Compaction characteristics were investigated using the following methods:

- moisture-density relationships using dynamic compaction (Standard Proctor Compaction tests),
- maximum and minimum density determinations.

The relationships defined above were used to select a material density for use in evaluating the relative permeabilities, consolidation characteristics and strength parameters. Permeability tests and consolidation tests were performed on prepared specimens.

The relative strength of the materials was evaluated using the following methods:

- direct shear tests (DS)
- uniaxial compression (unconfined compression) tests (Qu)
- unconsolidated, undrained triaxial tests with pore pressure measurements (UU)
- consolidated, undrained triaxial tests with pore pressure measurements (CU)

The data generated by the testing program was compiled graphically and analyzed by PCS Mining, Environmental Affairs.

5.0 LABORATORY TESTING PROGRAM

5.1 Terms and Definitions

Because of the uniqueness of the salt crystals present in the samples, many standard soil mechanics applications are not entirely applicable to this study. Some of the modifications or unique definitions of material properties are discussed below.

5.1.1 Water Content

In standard soil mechanics practice, water content is expressed as the percentage of water by dry weight of the soil sample, i.e.

$$W/C(\%) = (W_{water}/W_{soil}) \times 100$$

The weights are determined by oven drying the soil sample.

Where the pore fluid consists of saturated brine (water saturated with dissolved salt), following the standard procedure results in re-crystallization of the dissolved salt during the drying process. To describe the sample correctly, the dissolved salt content of the fluid must be considered and corrected for. This results in the following definitions:

W_{soil} = mass of insoluble minerals
W_{crys} = mass of salt crystals
W_{dis} = mass of dissolved salt
W_{water} = mass of pure water
W_{solids} = mass of solids
$= W_{crys} + W_{soil}$

Thus,

$$\text{Solids content} = W_{solids}/(W_{solids} + W_{water} + W_{dis})$$
$$= W_{solids}/(W_{soil} + W_{crys} + W_{water} + W_{dis})$$

$$\text{Crystalline salt content} = W_{crys}/(W_{soil} + W_{crys})$$

$$\text{Insoluble content} = \text{W.I.} = W_{soil}/(W_{soil} + W_{crys})$$

Water content may be expressed on the basis of total salt content (including dissolved salt) or on the basis of the soilds content only. These are defined as:

Unadjusted water content =

$$W/C_{un} = W_{water}/(W_{soil} + W_{crys} + W_{dis})$$

Adjusted water content =

$$W/C_{ad} = W_{water}/(W_{soil} + W_{crys})$$

When the pore fluid consists of saturated brine, the difference in the water content calculated becomes significant, therefore, the correction for dissolved salt content has been adopted to more properly reflect the sample composition prior to drying. Unless noted otherwise, the term water content refers to the adjusted water content throughout this report.

5.1.2 Dry Density

Since measurement of dry density includes measuring the water content, the above variation is incorporated into this test and to be consistent, densities must also be adjusted to account for dissolved salt, resulting in the following definitions:

Unadjusted dry density = $(W_{soil} + W_{crys} + W_{dis})/(1 + W/C_{un})$

Adjusted dry density = $(W_{soil} + W_{crys})/(1 + W/C_{ad})$

5.1.3 Curing

Because salt crystals seem to exhibit increasing cementation with increases in drying time, time effects would influence the properties, particularly strength. Curing time refers to the elapsed time after molding that a sample is exposed to drying conditions before testing.

5.2 General

Quality control in the handling of materials, preparation of test specimens and testing techniques were considered critical to the success of the program and stringent criteria were established to maintain consistency throughout. Test specimens were maintained in controlled temperature and humidity environments within the laboratory where possible.

5.3 Sample Composition

The samples as obtained the in field were analyzed to determine their composition. The solids phase of the samples consisted of the following components:

Cory - Slimes
- 34% water insolubles
- 66% salt crystals

Rocanville - Slimes
- 10% water insolubles
- 90% salt crystals

Cory - Salt Tails
- 98-99% salt crystals
- 1-2% water insolubles

Rocanville - Salt Tails
- 97% salt crystals
- 3% water insolubles

Test specimens were formed using the above sample compositions to duplicate the conditions of discharge from the mill.

Samples to determine the properties of the water insolubles were prepared by removing all of the salt crystals and dissolved salt from the slimes sampled to achieve a virtually salt-free test specimen.

The effects of the water insoluble content on the properties of the salt tailings was investigated by reconstituting samples in the laboratory and preparing test specimens in predetermined proportions. At Cory, the sampled slimes contained 34% insolubles and two additional combinations were selected for testing, namely 10% insolubles and approximately 20% insolubles. At Rocanville, only 10% of the solids in the samples obtained consisted of insolubles, thus additional compositions of approximately 20% and approximately 34% were selected to correspond with the Cory samples.

For purposes of identification throughout the program, the five categories of materials were designated as "A", "B", "C", "D" and "E". The categories differed in the percentage, by dry weight, of water insolubles (denoted as "W.I.%") of the total solids phase. These categories are summarized in Table 5.1.

5.4 Mineralogical Analyses

As discussed in Section 4, mineralogical analyses were conducted on representative samples of the water insoluble minerals present in the slimes. The results of these quantitative analyses have been presented in Section 4. The major significance to the physical testing program is the higher percentage of clay in the samples from PCS Mining Cory Division, or conversely, the higher percentage of quartz and dolomite in the samples from PCS Mining Rocanville Division.

5.5 Chemical Analyses

As discussed in Section 4, the chemical composition of the salt tails was determined by the PCS Mining laboratory. The results of these analyses are presented in Section 4 and confirm NaCl as the major constituent.

5.6 Preparation of Samples for Physical Tests

Procedures were developed for preparing each type of material for testing.

Material A - Material A (insolubles) was produced from Material B (slimes), using the following "washing procedure.

- several pails of "as delivered" slimes were intermixed and excess brine was decanted off.
- the material was placed in a 500 gallon tank which was then filled with water.
- the material was allowed to soak for at least one day, then the excess water was pumped off.
- the soaked soil was placed inside an annular filter cloth and centrifuged to remove excess water.

Table 3.1
Composition of Test Specimens

SAMPLE DESIGNATION	Water Insoluble Content	Salt Content
Cory Division		
A-Washed Slimes	100.%	0
B-Slimes as Sampled	34.%	66.%
C-Salt Tails as Sampled	1.%	99.%
D-Composite Lab Sample	10.%	90.%
E-Composite Lab Sample	17.%	83.%
Rocanville Division		
A-Washed Slimes	100.%	0
B-Slimes as Sampled	10.%	90.%
C-Salt Tails as Sampled	1.%	99.%
D-Composite Lab Sample	32.%	68.%
E-Composite Lab Sample	19.%	81.%

- the conductivity of the water removed by the centrifuge was measured.
- the soil was re-soaked and re-centrifuged. This procedure was repeated until the conductivity was below 2 000 micro mhos.

Following washing, the material was either air dried or dried in an oven at 110°C.

Material B - Excess brine was decanted off several pails of "as delivered" slimes. The material was then spread out in a 1.8 metre by 1.8 metre drying frame. The material was then intermixed and it was allowed to air dry for several weeks until a workable water content was obtained. (Adjusted water contents of about 7.9% and 19.1% were recorded for "air dried" B material from Cory and Rocanville respectively.

Material C - Excess brine was decanted off selected pails of salt tails. The material was then spread out in a 1.8 metre by 1.8 metre drying frame and it was intermixed and allowed to dry for a period of over one week. After time this, water contents of about 6.1% and 4.2% were obtained for Cory and Rocanville, respectively. Some cementation between grains did occur during drying. Agglomerations of particles were gently broken up on several occasions during the drying period.

Materials D and E - These materials were prepared by mixing oven dried C and A in the proper weight proportions.

5.7 Water Insoluble Contents

By definition, water insoluble content = $W_{soil}/(W_{soil} + W_{crys})$

Two methods were used to determine water insoluble contents as follows:

- The insoluble content of "as delivered" material B was determined by determining the weight loss of samples in the course of "washing".

- For all other materials the W.I.% was determined using a suction filter. Each sample was oven dried and weighed. It was then soaked overnight in distilled water and poured through a funnel lined with a fine filter paper of known weight. Vacuum was applied at the base of the funnel to assist drainage. The material retained on the filter paper was oven dried at 110°C and re-weighed along with the filter paper. It was then re-soaked and poured through the filter paper. This procedure was repeated until a constant weight was obtained. The weight loss was computed, taking into account a correction for the initial moisture content of the filter paper.

5.8 Dissolved Salt Content of Brine

Throughout the testing program, determinations were made of the dissolved salt content of the brine being used as a mixing fluid. This was done simply by determining the residue remaining after evaporation of all water.

5.9 Specific Gravity of Particles

The specific gravity of the insoluble particles was measured using the pycnometer method described in ASTM Designation D854-83. The specific gravity of the salt crystals was measured using the same method except that kerosene was used to fill the pycnometer instead of water. The specific gravity of the kerosene used in the testing was measured to be 0.799 at 20°C. Tests were also run on the slimes samples using the kerosene to determine the effectiveness of this method on combined particles.

The results of the specific gravity tests are shown on Figure 5.1. The results seem erratic and vary from expected values. The specific gravity of the salt tails was measured to be 2.10 to 2.12. Similar tests conducted by the University of Saskatchewan measured the specific gravity of Rocanville salt tails to be 2.17. The values for combined samples of salt tails and insolubles were measured well above the specific gravity calculated from the

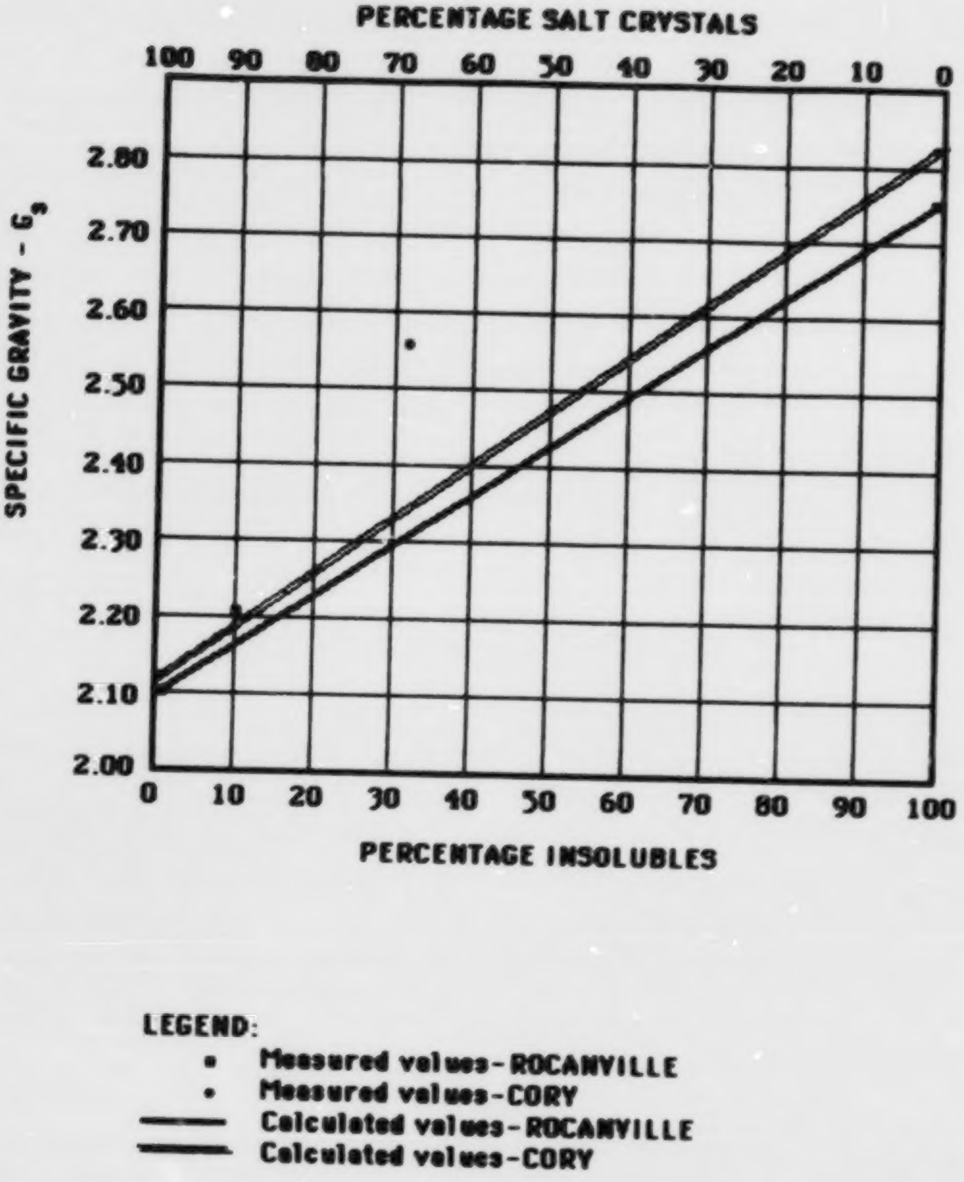


Figure 5.1

SPECIFIC GRAVITY OF SALT TAILS AND INSOLUBLES individual constituents. The testing procedures were reviewed however, the discrepancies cannot be explained. Further testing will be required to confirm the accuracy of the testing procedure and to assess the variations indicated.

5.10 Grain Size Distribution

The grain size distribution of the salt tails (Material C) was determined using mechanical analyses as defined by ASTM Specification D422-63. The entire sample was dry sieved through a nest of sieves and the results are expressed as the percentage of the total mass passing (smaller than) each sieve size.

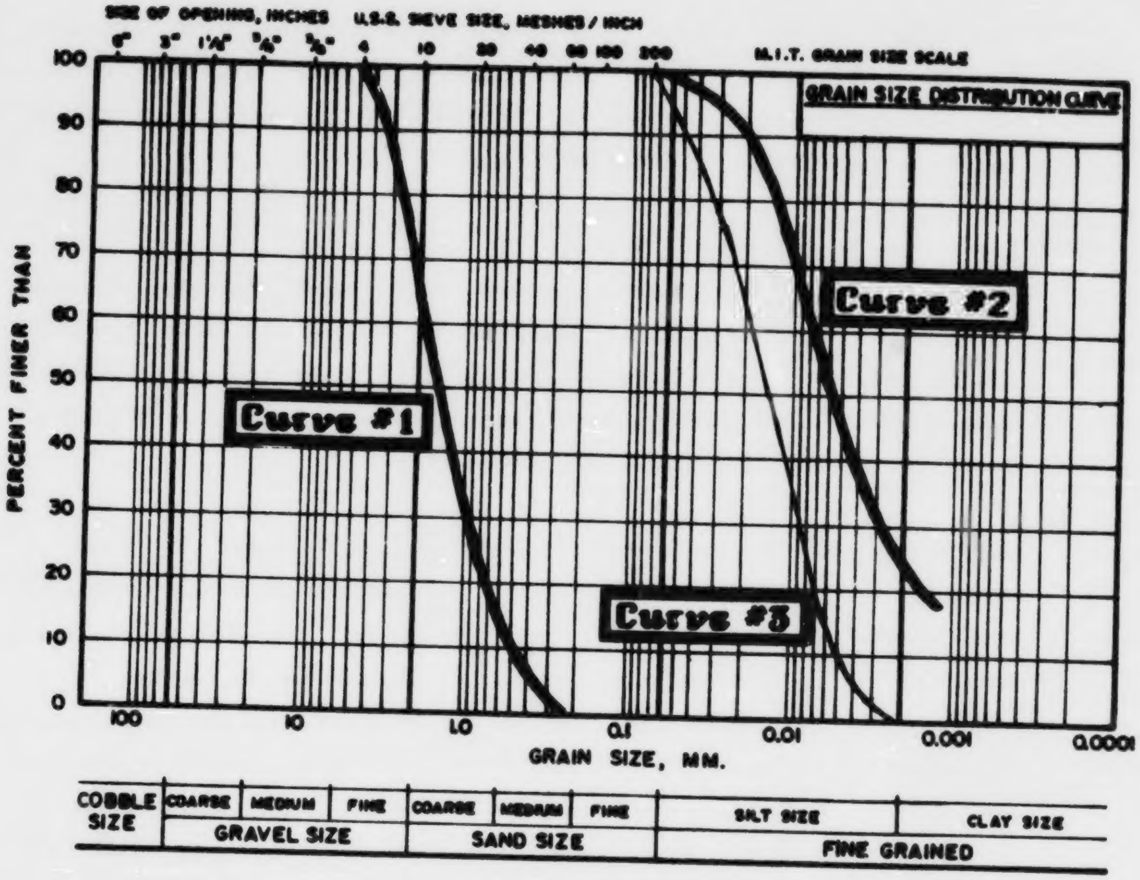
Difficulty was experienced in performing this test in that it required drying of the sample prior to sieving. The air drying of the sample results in mild cementation of the particles into conglomerates. The cemented particles must then be broken up to restore the sample to its original grain size distribution. This procedure of breaking up the sample becomes very subjective and may be very sensitive to the judgement employed. In an attempt to eliminate personal bias, the test was repeated by different technologists. Results were reproduced with reasonable success. The time of mechanical sieving was varied to assess its effects if any, however, little variation in grain size was apparent for sieving times of ten minutes or more.

Some experimentation was attempted to develop a more reliable and reproducible method of determining grain size, such as employing wet methods. These met with little success in the preliminary efforts and were abandoned in this study.

The results of the dry sieving are plotted on Figures 5.2 and 5.3. The uniformity coefficient, Cu (an expression of the degree of uniformity of the material) is calculated to be:

Cory - salt tails - Cu = D60/D10 = 2.3

Rocanville - salt tails - Cu = D60/D10 = 4.0



Legend of Plots:

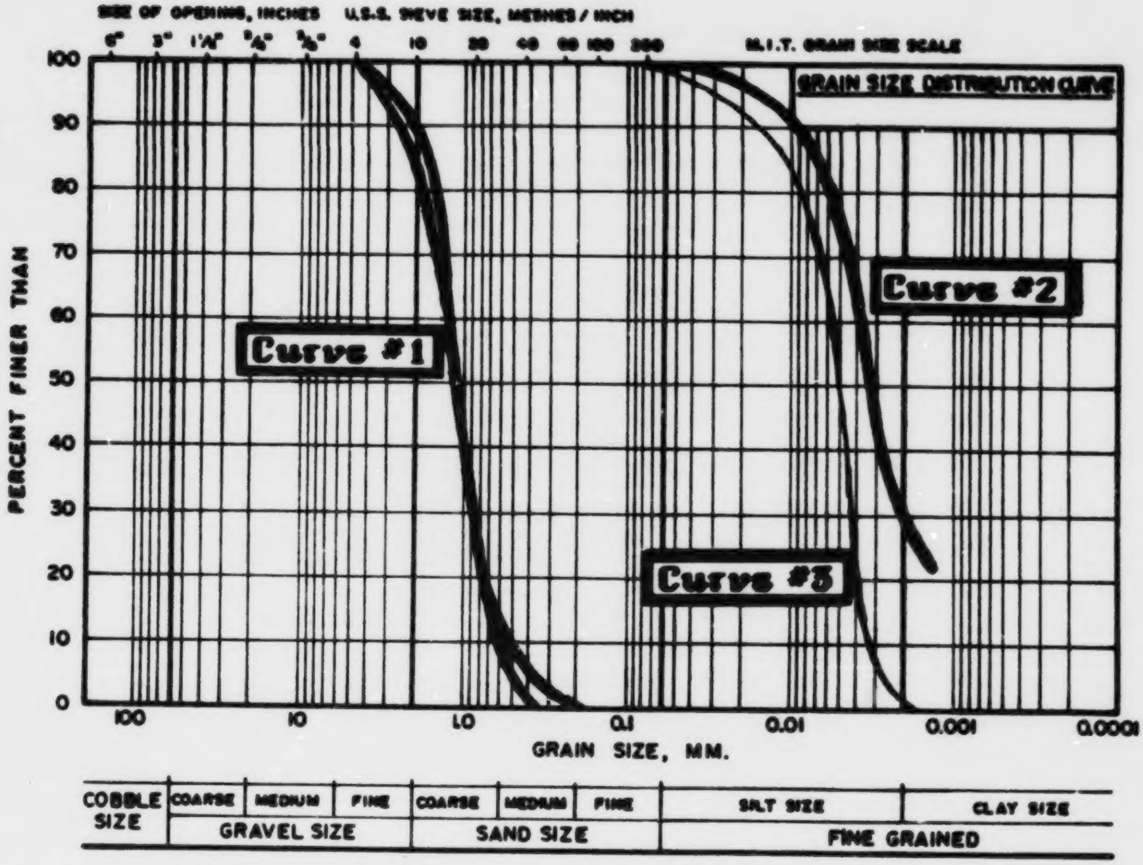
Curve #1 – SALT TAILINGS (Rocanville)

Curve #2 – WATER INSOLUBLES (Rocanville)
HYDROMETER PERFORMED AFTER ADDITION
OF HEXAMETAPHOSPHATE

Curve #3 – WATER INSOLUBLES (Rocanville)
HYDROMETER PERFORMED AFTER ADDITION
OF LIGNOSULPHONATE

Figure 5.2

GRAIN SIZE DISTRIBUTION
SALT TAILS AND INSOLUBLES
ROCANVILLE SAMPLES



Legend of Plots:

Curve #1 – SALT TAILINGS (Cory)

Curve #2 – WATER INSOLUBLES (Cory)
HYDROMETER PERFORMED AFTER ADDITION
OF HEXAMETAPHOSPHATE

Curve #3 – WATER INSOLUBLES (Cory)
HYDROMETER PERFORMED AFTER ADDITION
OF LIGNOSULPHONATE

Figure 5.3
GRAIN SIZE DISTRIBUTION
SALT TAILS AND INSOLUBLES
CORY SAMPLES

where D60 = particle diameter at 60% passing
D10 = particle diameter at 10% passing

The uniformity coefficients of 4 or less represent a very uniform material.

The grain size distribution of the water insolubles (Material A) was determined using the Hydrometer test, ASTM Specification D422-63. Water was used as the suspending medium since the salt crystals were removed. During the beneficiation process a flocculating agent is added and presumably some of this remains within the slimes and may not be removed by the washing process. This would seem to be the case as the particles showed a strong tendency to flocculate very quickly after mixing. Two types of dispersant were used to perform the test, i.e. hexametaphosphate and lignosulfonate and the results compared. The hexametaphosphate indicates a smaller grain size, is consistent with the mineralogical analyses of the insolubles and appears to be effective. The lignosulfonate was not effective as a dispersant.

The results obtained from the hydrometer tests are illustrated on Figures 5.2 and 5.3. The insolubles are a very fine grained particle size and are relatively uniform materials.

The effectiveness of the hydrometer test in measuring the grain size distribution of samples containing both insoluble particles and salt crystals was evaluated. Since water cannot be used as the suspending medium, three other media, kerosene, brine and detergent were tried in conjunction with the dispersants. None of the attempts were successful.

Table 5.2 summarizes the hydrometer techniques and the results that were obtained.

Table 5.2

Effects of Suspending Media and Dispersants on Hydrometer Tests

MATERIAL		SUSPENDING MEDIUM	DISPERSANT USED	RESULT
A-Insolubles	-	Water	Hexametaphosphate	Excellent
	-	Water	Lignosulphonate	Flocculation occurs
B-Mixture of Salt & Insols	-	Brine	None	Flocculation occurs
	-	Brine	Hexametaphosphate	Hexametaphosphate not soluble in brine
	-	Brine	Lignosulphonate	Lignosulphonate not soluble in brine
	-	Kerosene	Hexametaphosphate	Hexametaphosphate not soluble in kerosene
	-	Kerosene	Lignosulphonate	Lignosulphonate not soluble in kerosene
	-	Kerosene	None	Unable to achieve suspension of particles
	-	Detergent	None	Salt disolves

5.11 Atterberg Limits

Atterberg Limit determinations were made on a number of samples of varying proportions of insoluble materials and salt crystals.

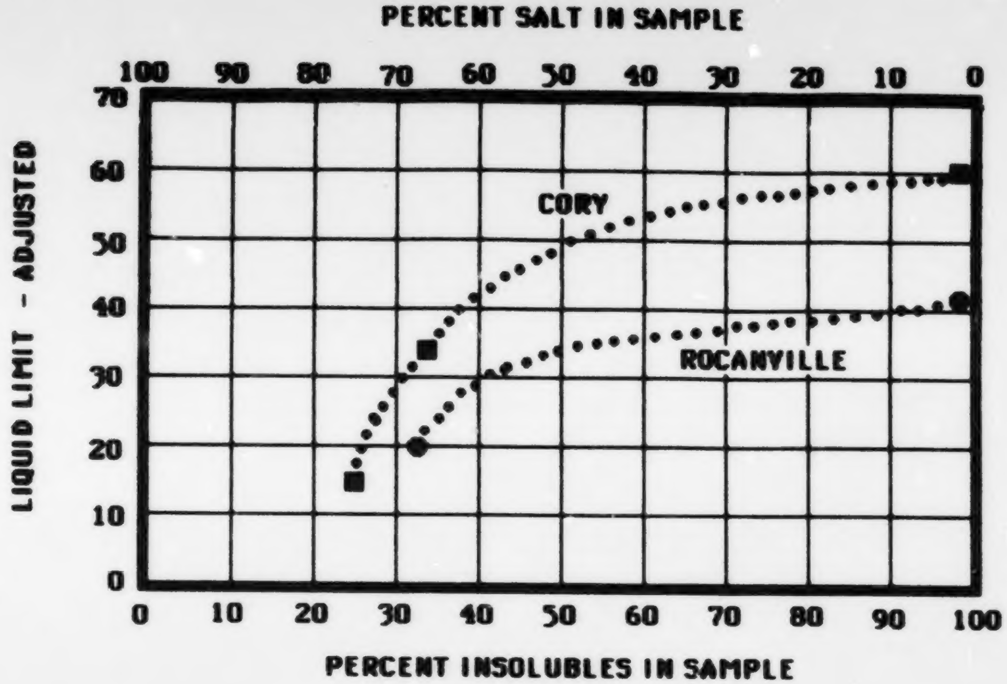
The standard ASTM Specification D4318-83 includes drying, grinding and re-wetting of soil samples. This specification was used for salt free samples (Material A) however, for samples containing salt crystals, this was not considered appropriate. Drying of the samples would cause dissolved salt to crystallize and effect the results, i.e.:

- increased salt content may affect the double layers in the clay, altering plasticity,
- the increased presence of salt crystals may result in a more granular sample.

To minimize the amount of dissolved salt crystallizing, a centrifuge was used to drain the slurry down to near the liquid limit. The liquid limit was then determined in the normal manner. Because centrifuging would not drain the sample down to the plastic limit, air drying was used to reduce the water content from the liquid limit to the plastic limit. The plastic limit was then determined in the standard manner. Brine was used as the pore fluid in all samples containing salt crystals. All water contents were corrected for dissolved salt and the limits are expressed as adjusted water contents.

The Atterberg limit determinations are summarized in Figure 5.4. The limits determined are considerably different than previous testing (BBT, 1983). Results obtained herein indicate that the Cory washed slimes (insolubles) classify as a highly plastic material.

Because of the possible anomolies in the Atterberg limits, PCS Mining requested that tests be repeated. Results were confirmed by the materials testing laboratory (Golder Associates).



Atterberg Limit Determinations

SAMPLE DESCRIPTION	ATTERBERG LIMITS (adjusted water contents- %)		
	LIQUID LIMIT	PLASTIC LIMIT	PLASTIC INDEX
Cory A-insolubles	60.0	22.0	38.0
Cory B-34% insolubles	34.0	14.0	20.0
Cory--25 % insolubles	14.5	13.0	1.5
Cory--17 % insolubles		non plastic	
Rocanville A-insolubles	41.0	21.0	20.0
Rocanville--32 % insolubles	22.0	20.0	2.0
Rocanville--25 % insolubles		non plastic	

Figure 5.4

SUMMARY OF ATTERBERG LIMIT DETERMINATIONS

5.12 Moisture-Density Relationships

The dynamic compaction characteristics were carried out using the procedures specified by ASTM Specification D698 Method D (commonly referred to as the Standard Proctor Compaction Test). The test was modified to accommodate samples containing salt crystals in that saturated brine which was used as the mixing fluid to prevent dissolving of the salt crystals. The purpose of the test was to establish the moisture-density relationship for a constant dynamic compactive effort (constant energy). This relationship provides information on the compactibility of the material, the optimum water contents to achieve maximum density and was used as a guideline in selecting the moisture-density parameters to be used preparing specimens for strength testing.

In addition, the maximum and minimum densities, as defined by ASTM Specifications D 4-253-83 and D 8254-83, were determined for samples containing 80% or greater salt crystals. The minimum density determination was performed in accordance with the ASTM method while brine was substituted for the water specified by ASTM for the maximum density determination. In applying the ASTM procedure for maximum density determination, both the wet and dry method were tried with the wet method yielding the maximum values for maximum density.

The results of the Standard Proctor Compaction tests are presented graphically in Figures 5.5 and 5.6 and are summarized in Table 5.3. Minimum and maximum density determinations are also summarized in Table 5.3.

With the exception of the salt tails the samples exhibited moisture-density relationships of a curved shape typical of those obtained for cohesive, mineral soils tested in a non-salt environment. In subjecting the salt tailings to dynamic compaction in a mold, water drained from the sample if the mixing water content was above 12 to 16% (12%) in the case of Rocanville salt tails and 16%

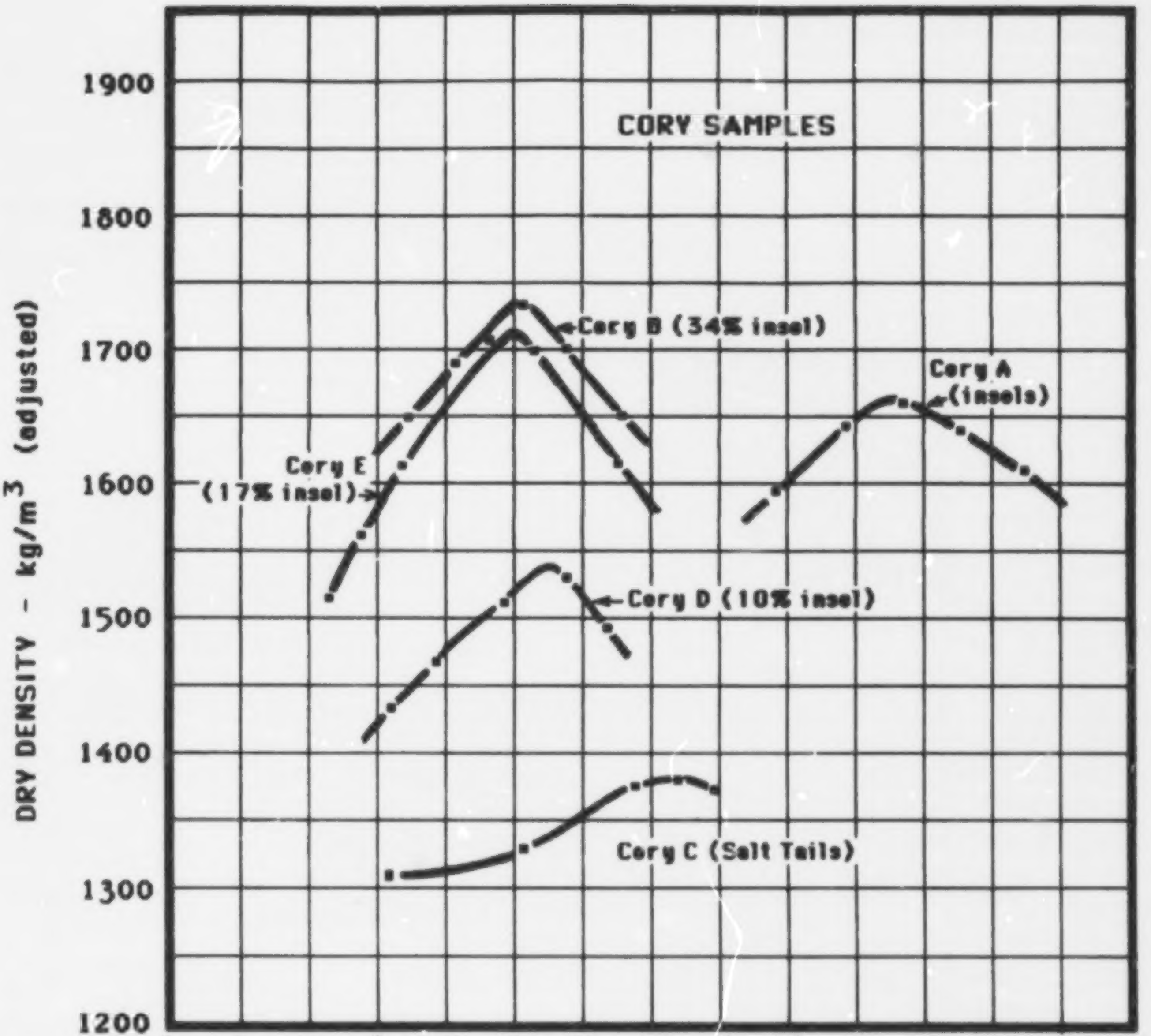


Figure 5.5

MOISTURE DENSITY RELATIONSHIPS
(Standard Proctor Compaction Tests)
PCS Mining CORY Division Samples

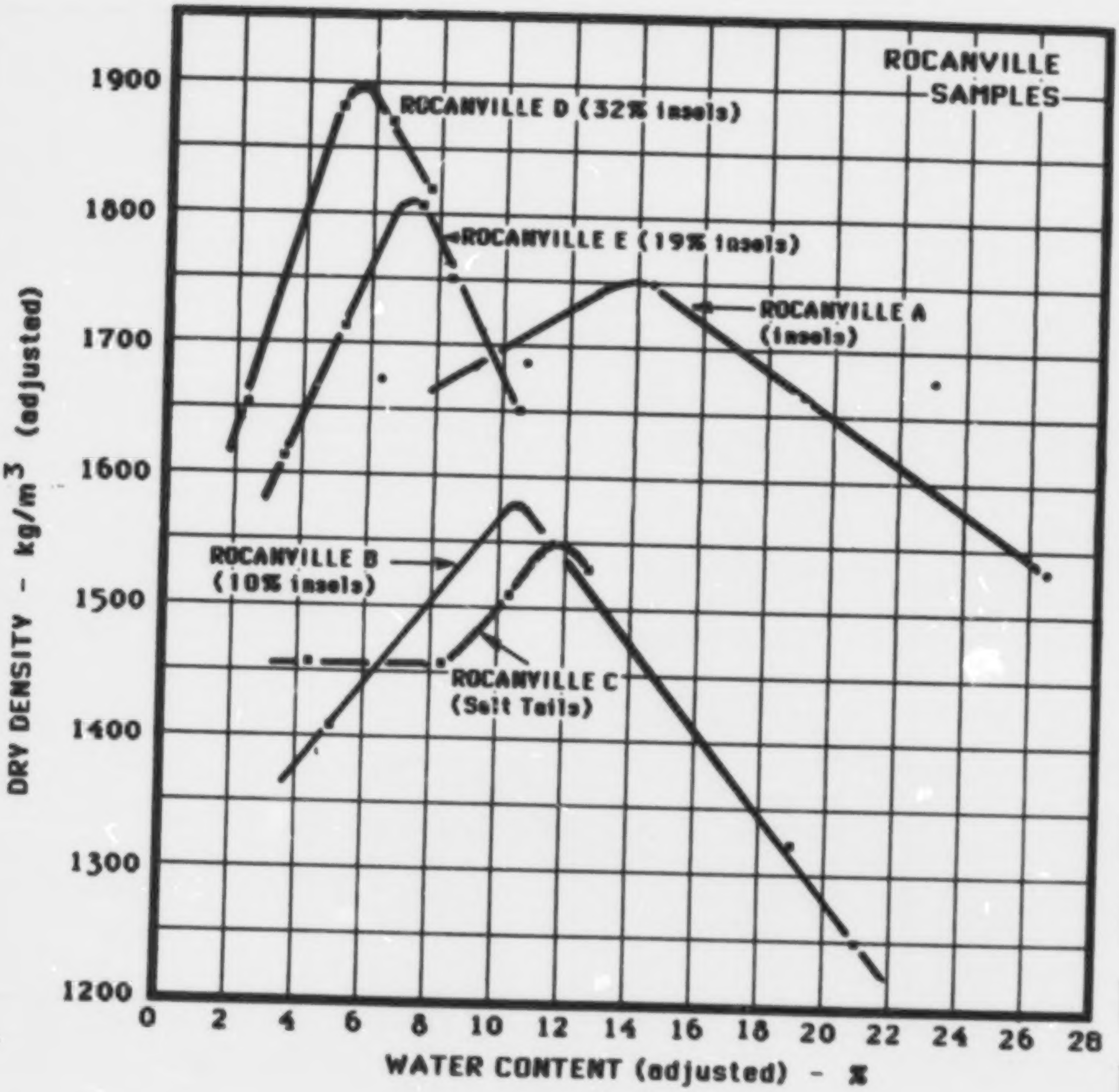


Figure 5.6

MOISTURE DENSITY RELATIONSHIPS
(Standard Proctor Compaction Tests)
PCS Mining ROCANVILLE Division Samples

Table 5.3

Summary of Moisture-Density Relationships and Relative Density Determinations

SAMPLE	STANDARD PROCTOR TEST		MIN-MAX DENSITY	
	MAX DRY DENSITY (kg/m^3)	OPTIMUM WATER CONTENT %	MINIMUM DENSITY (kg/m^3)	MAXIMUM DENSITY (kg/m^3)
CORY				
A-insolubles	1665.	21.5	---	---
B-34% insols	1735	10.3	---	---
E-17% insols	1710.	10.0	1195.	1560.*
D-10% insols	1540.	11.0	1180.	1460.*
C-Salt Tails	1380.	14.5	1100.	1350.
ROCANVILLE				
A-insolubles	1750.	14.0	---	---
D-32% insols	1900.	5.5	---	1305.*
E-19% insols	1810.	7.0	1250.	1620.*
B-10% insols	1580.	10.5	1080.	1360.*
C-Salt Tails	1550.	11.5	1130.	1425.*

Notes: * Maximum density determinations less than maximum densities determined by Standard Proctor Test reflect the inaccuracy or non - applicability of the Maximum Density Test when applied to salt tails.

in the case of Cory salt tails). Thus, any addition of mixing water above that point was lost and the measured water content and dry density remained relatively constant. This yields moisture-density curves which are more typical of a uniform mineral sand. The test results on salt tails may indicate that source or refining process has an effect on compactibility characteristics of salt tailings.

The compaction tests indicate that the addition of a small amount of insolubles to salt tailings has a dramatic effect on the compactibility characteristics of the material as illustrated in Figures 5.7 and 5.8. The addition of 10% insolubles to the salt tailings is sufficient to result in moisture-density curves more typical of cohesive mineral soil. The addition of insolubles results in an increase in the maximum density achieved using a constant compactive effort. Maximum dry densities are achieved at an insoluble content of approximately 30% with a more gradual decrease in density beyond that content. The converse is true with the optimum water content for compaction. These results compare very favorably with the moisture-density relationships reported by BBT Geotechnical Consultants (1983), however, the compaction test results indicate a different relationship than those reported by the University of Saskatchewan (1982). That report indicated that the addition of 10% insolubles had little or no effect on the moisture-density relationship, in contrast to the marked effects noted in this study.

The dynamic compaction test conducted on salt tails in this and the other referenced studies is a very rapid test. The material is initially dried, broken up and the mixing fluid is added in a pre-determined quantity. The material is then placed in the mold and the compactive effort is applied rapidly in a matter of minutes. The time frame is insufficient for significant cementation or plastic deformation of the salt crystals to occur and thus, the salt tailings apparently react in the same fashion as a granular material.

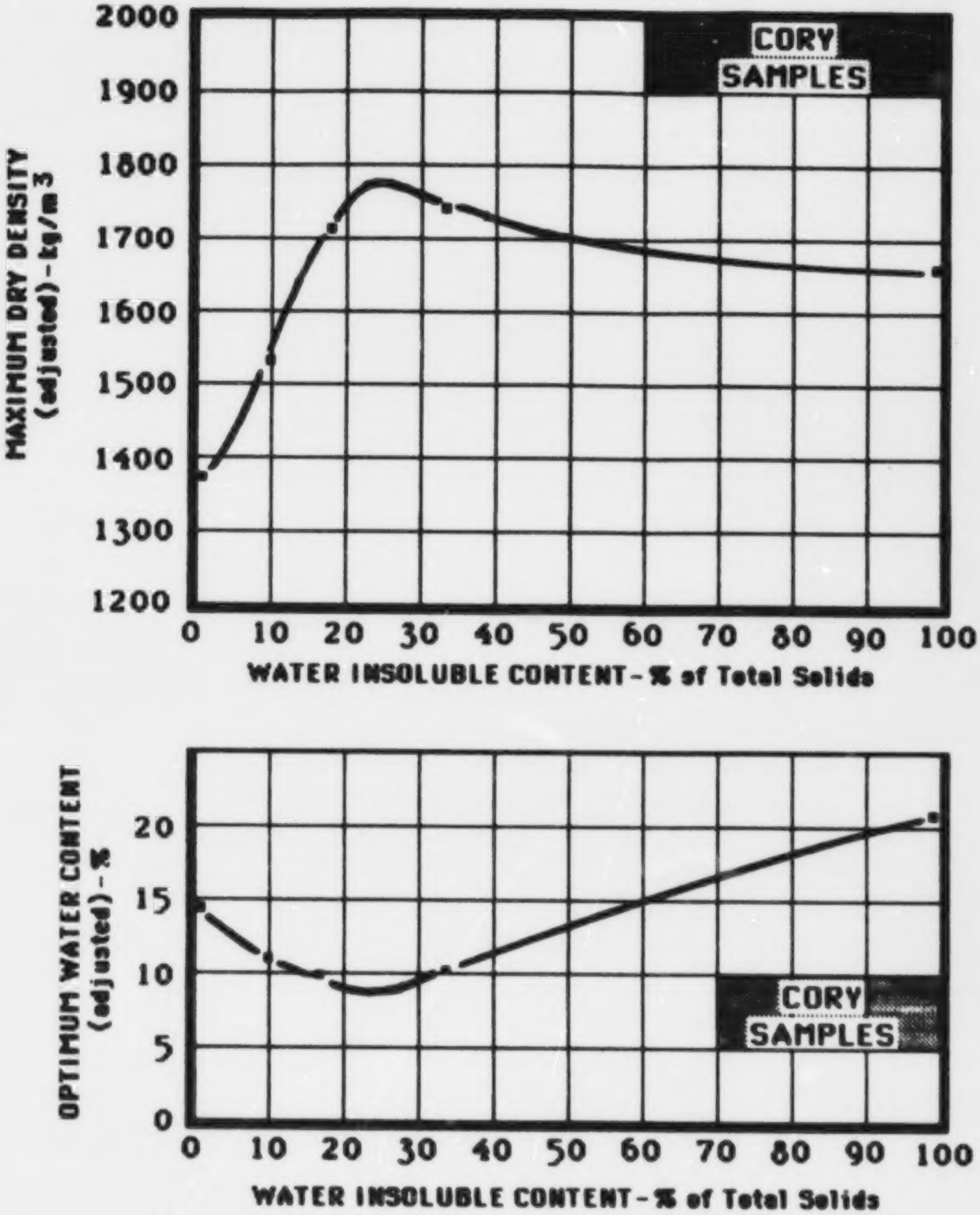


Figure 5.7

RELATIONSHIP BETWEEN MAXIMUM DRY DENSITY, OPTIMUM WATER CONTENT AND WATER INSOLUBLE CONTENT PCS Mining CORY Division Samples

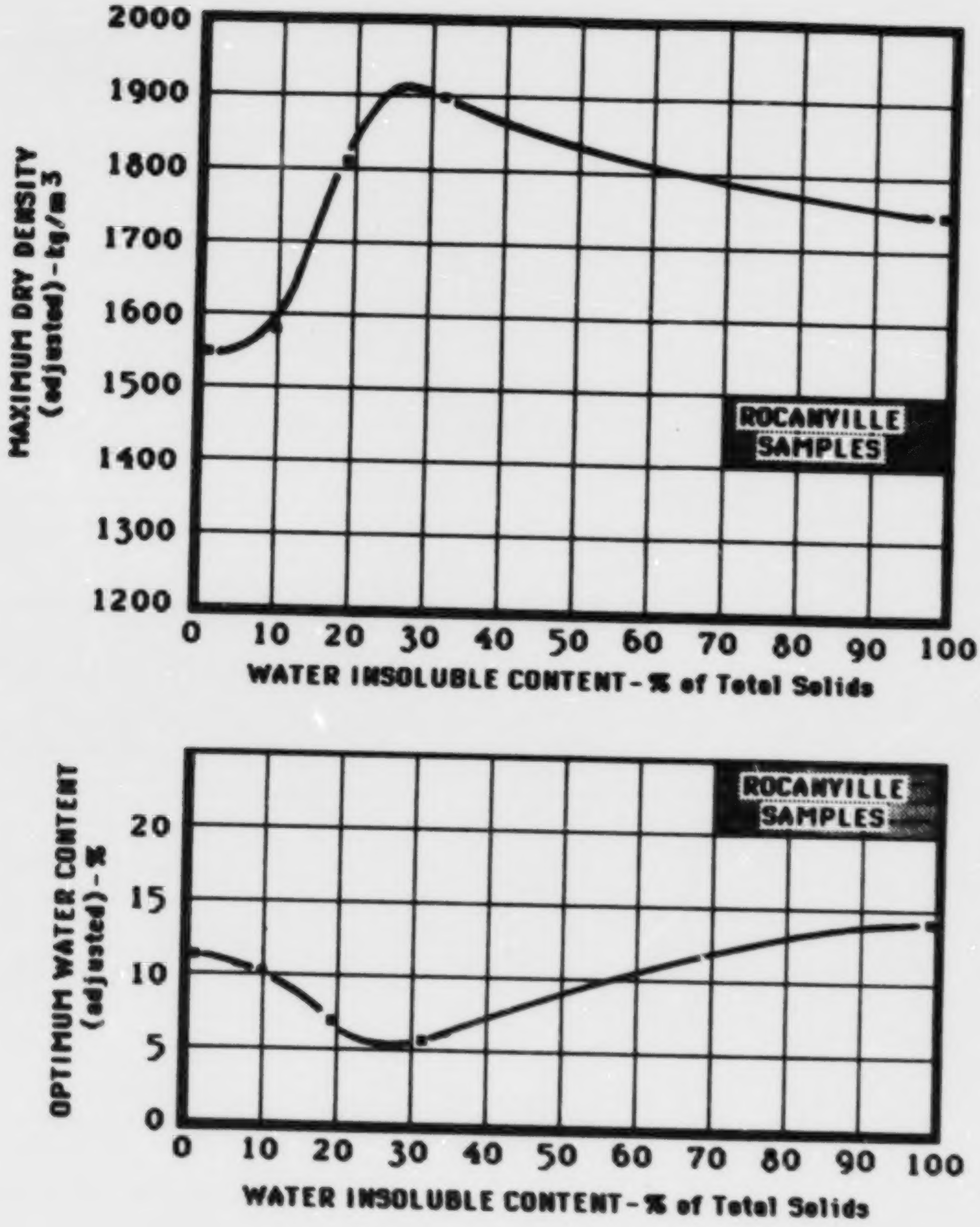


Figure 5.8

RELATIONSHIP BETWEEN MAXIMUM DRY DENSITY, OPTIMUM WATER CONTENT AND WATER INSOLUBLE CONTENT PCS Mining ROCANVILLE Division

5.13 Sample Preparation for Strength, Consolidation and Permeability Testing

A number of variables are known or expected to influence the strength, consolidation and permeability characteristics of prepared samples, particularly those containing salt crystals. Among these are the molding density, water content and the elapsed time between molding and testing. In order to evaluate the effects of the addition of insolubles to salt tails, or vice versa, it was desirable to maintain as many other variables as possible constant. It was therefore concluded that the initial or molding densities and the "curing time" of samples must have some reasonable correlation. In selecting density, a reasonable procedure is to compare the samples using uniform compactive effort. It was considered that the Standard Proctor test would provide a reproducible standard and it was selected as a definition of densities and water contents to be used in sample preparation. One notable exception was the salt tails. In view of the previous studies of salt tails, it was considered prudent to select densities consistent with those studies so that a direct comparison of results could be made. Based on these criteria, the "target" or pre-determined densities were selected as shown in Table 5.4.

Having selected the desirable initial density and water content for the test specimens, the physical means of preparing the samples were considered. Considering the present method of placement in the field, i.e., spiggoting in an upstream placement procedure, dynamic compaction is unlikely to simulate in-situ conditions. A static compaction procedure was considered more representative of the field conditions and this procedure was selected. Thus, test specimens were produced by statically compacting a fixed mass of material at a known water content in a mold of known volume.

5.14 Permeability

Permeability may be defined as the facility with which water is able to travel through the pores of the material. The soil permeability

Table 5.4
Target Densities for Preparation of Samples for Consolidation, Permeability and Strength Testing

MATERIAL DESCRIPTION	TARGET DRY DENSITY (kg/m^3)	OPTIMUM WATER CONTENT %
CORY A-INSOLUBLES	1665.	21.5
CORY B-34%-INSOLUBLES	1735.	10.3
CORY C-SALT TAILS	1600.	14.5
CORY D-10%-INSOLUBLES	1540.	11.0
CORY E-17%-INSOLUBLES	1710.	10.0
ROCANVILLE A-INSOLUBLES	1750.	14.0
ROCANVILLE B-10% INSOLUBLES	1580.	10.5
ROCANVILLE C-SALT TAILS	1600.	11.5
ROCANVILLE D-32% INSOLUBLES	1900.	5.5
ROCANVILLE E-19% INSOLUBLES	1810.	7.0

is defined by the coefficient of permeability, k. The coefficient of permeability as used in this report is the engineers' coefficient or Darcy's coefficient and is defined as the discharge velocity through a unit area under a unit hydraulic gradient. Numerous factors influence permeability, including:

- -viscosity of the fluid
- -grain size distribution
- -void ratio or porosity
- -shape and arrangement of pores
- -soil structures

Normally permeability tests are conducted on soils using pure water, however, in the case of salt tails, the use of water would result in dissolving of salt crystals. In order to simulate the actual field conditions, the permeability determinations on samples containing salt crystals were made using a saturated brine solution. Thus, permeabilities on such samples are expressed in terms of saturated brine as the pore fluid. Since the viscosity of saturated NaCl brine is approximately twice that of water, brine will flow through pores at a slower rate than water.

All variables effecting the permeability could not be assessed within the scope of this study therefore, the primary thrust was to assess the variation of permeability with changes in salt and insoluble content of the materials.

Samples to be tested were formed in a 100 mm diameter permeameter. Samples were compacted to a length of approximately 50 mm to the target density using static compaction procedures. A constant head permeability test was applied to the more permeable salt tails. A falling head permeability test was performed on all other samples. Water was used as the permeant for the pure insoluble materials (Material A) and saturated brine was used as the permeant for all samples containing salt crystals.

The measured permeabilities are illustrated in Figure 5.9. The plot of measured permeability (log scale) vs. insoluble content of the sample indicates a typical relationship for materials made up of clay mixed with coarse grained material. The coefficient of permeability decreases rapidly when insolubles are initially added to the salt tailings, levelling off to a minimal decrease beyond an insoluble content of 40% in the case of Cory materials and 60% in the case of Rocanville materials. As expected, considering the higher clay content of the Cory insolubles, a greater permeability was measured for the Rocanville materials.

The permeabilities of clays and silts can be calculated from the data recorded in laboratory consolidation tests. In this case, the calculated values of k for the pure insoluble samples (Material A) compare very favorably with the measured values, i.e.:

Cory Material A - 100% insolubles
k (measured) = 2.0×10^{-8} (falling head permeability test)
k (calculated) = 1.8×10^{-8} (from consolidation test)

Rocanville Material B - 100% insolubles
k (measured) = 1.6×10^{-7}
k (calculated) = 2.2×10^{-7}

As expected, the consolidation data does not provide a reliable compution of k for materials with a k below approximately 10^{-7} cm/sec.

Emperical computation of the coefficient of permeability from grain size distribution is relatively successful for clean sands. It was thought that a similar application may be made to salt tails however, applying the emperical relationships to the salt tails resulted in calculated values more than one order of magnitude greater than the measured values.

The measured values of the coefficient of permeability for the pure insolubles (Material A) would generally classify these materials as

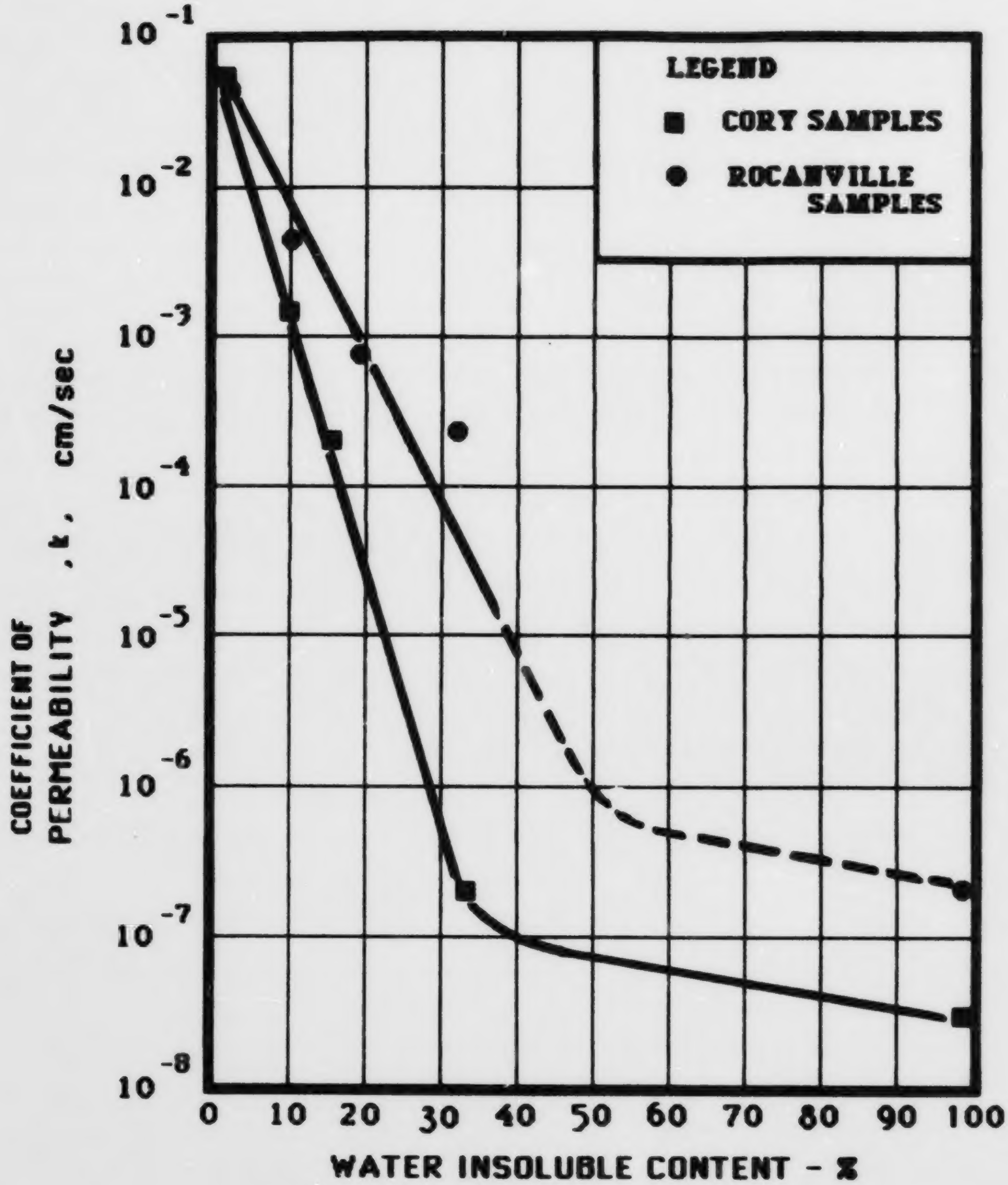


Figure 5.9

PERMEABILITY MEASUREMENTS
CORY AND ROCANVILLE SAMPLES

"practically impervious" (Terzaghi and Peck, 1948). The salt tails would classify as having a medium to high degree of permeability, similar to a clean sand. Increasing the insoluble content appears to result in a constant rate of decrease in permeability up to a critical insoluble content beyond which the rate of decrease in k drops dramatically. As Figure 5.9 illustrates, the effects of insolubles on the permeability of salt tails are very dramatic.

5.15 Consolidation

The compressibility of the materials was investigated using the one-dimensional consolidation test (ASTM Specification D 2435-65T).

Samples were prepared by static compaction to a pre-determined density and trimmed to fit 50 mm diameter consolidation rings. All specimens were flooded for testing, with Material A (insolubles) immersed in distilled water and all other samples containing salt crystals immersed in saturated brine. Loads were applied incrementally, starting at low stresses and doubling the stress to a maximum of approximately 4 000 kPa.

Because of the known time dependent creep behaviour of halite, a significant amount of creep would be expected under a constant load. This creep behaviour was investigated and well documented by the University of Saskatchewan (Pufahl and Yosheda, 1982). An attempt was made, therefore, to reduce the effects of plastic or viscoplastic flow in this series of testing and assess the primary consolidation characteristics only. This was done by applying each new load increment as soon as primary consolidation was complete. Samples were not rebounded to permit direct measurement on the sample at the conclusion of consolidation.

The results of the consolidation tests are summarized in Table 5.5 and are presented graphically on Figures 5.10 and 5.11. More detailed results are given in Appendix A. It is postulated that the consolidation of the specimens is comprised of elastic behaviour of

Table 5.5

Summary of One-Dimensional Consolidation Tests

MATERIAL	INITIAL DENSITY (kg/m^3)	INITIAL/ FINAL WATER	INITIAL VOID RATIO	COEFFICIENT OF CONSOLICATION
CORY A	1730	22.0/18.5	.61	.0025
CORY B	1610	15.5/6.7	.37	.0015
CORY C	1570	5.3/7.5	.34	.03 - .005
CORY D	1460	8.7/8.3	.49	.002
CORY E	1665	11.7/5.0	.35	.001
ROCANVILLE A	1730	21.2/15.8	.60	.0035
ROCANVILLE B	1400	15.1/3.7	.84	.002
ROCANVILLE C	1595	5.6/15.2	.32	.003
ROCANVILLE D	1740	8.5/7.1	.35	.001
ROCANVILLE E	1665	12.5/5.0	.34	.001

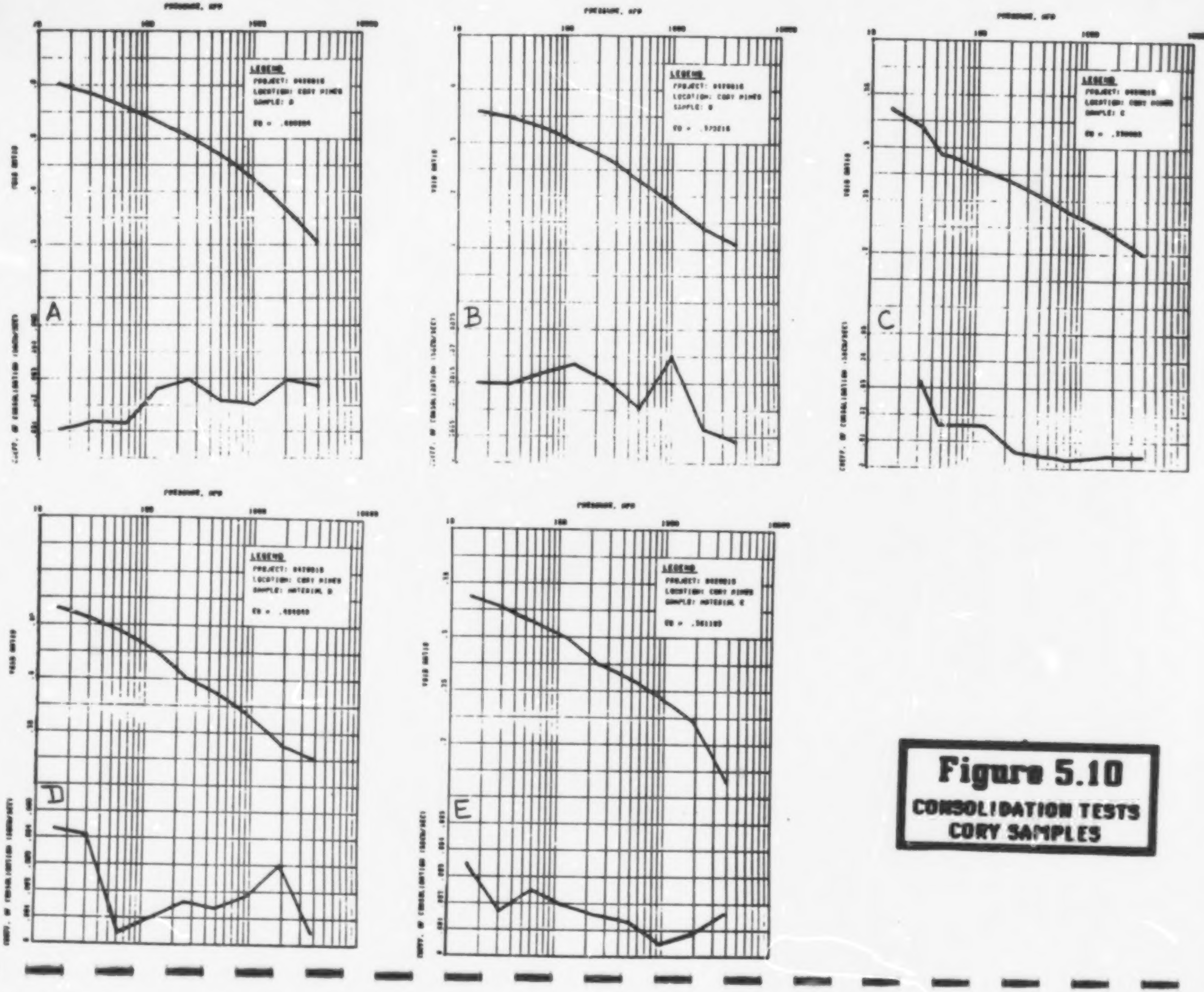


Figure 5.10
CONSOLIDATION TESTS
CORY SAMPLES

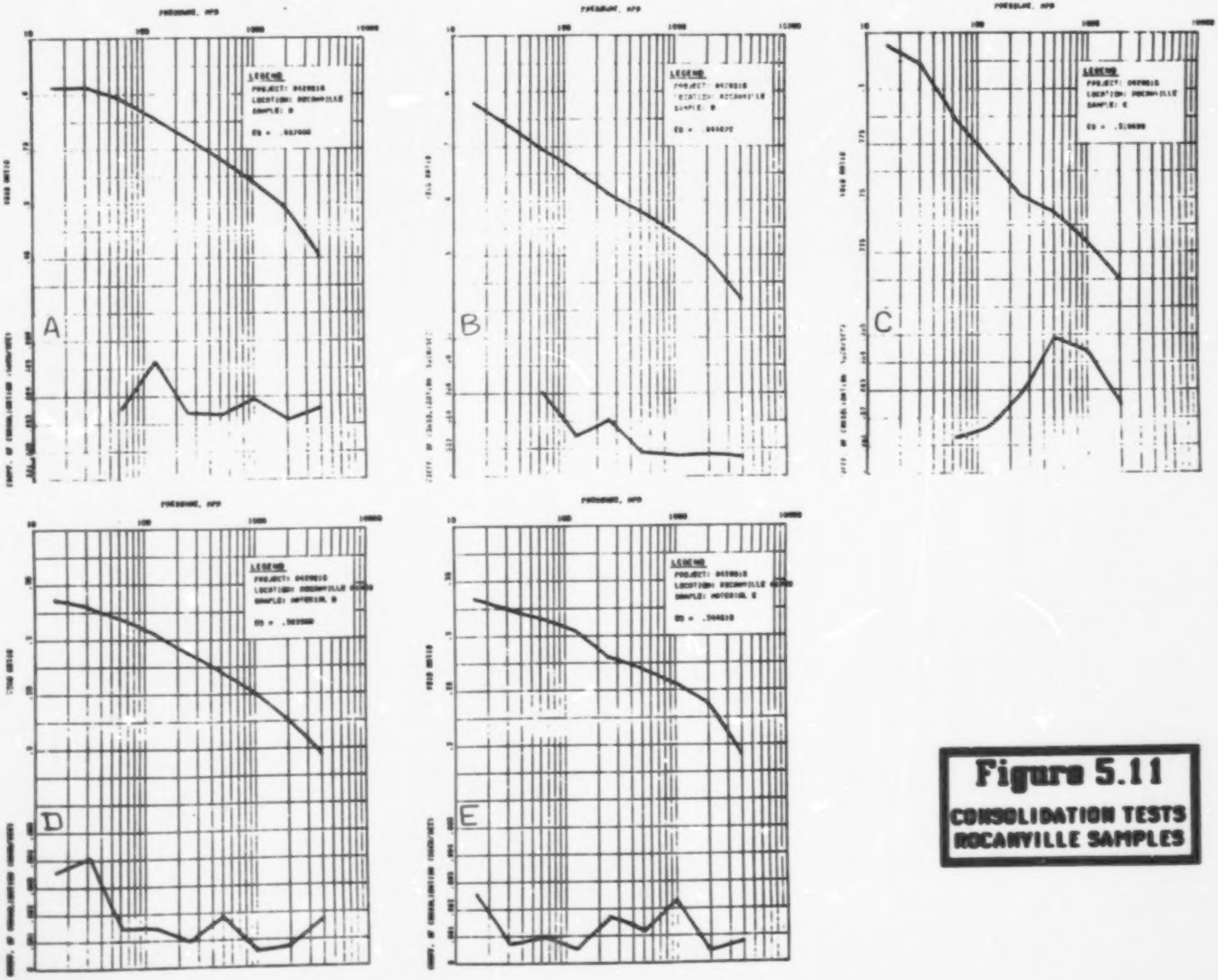


Figure 5.11

CONSOLIDATION TESTS
ROCANVILLE SAMPLES

the structure and rearrangement of the particles with little destruction or deformation of the individual salt crystals. The values of the coefficient of consolidation, Cv, were calculated at various times and stresses as shown on the plots. The values of Cv generally range from 0.001 to 0.005 cm^2/sec. Values such as this would be indicative of a soil which has a relatively low permeability. This would be expected for the samples with high insoluble contents however, values in excess of 0.01 cm^2/sec would be expected for free draining materials such as salt tails. Thus, the consolidation test results do not conform to standard soil mechanics theory in the case of samples containing less than 30% insolubles. Those samples containing greater than 30% insolubles seem to follow classical consolidation theory for soils.

5.16 Strength Testing

The shear strength is defined as the maximum resistance of a soil to shearing stresses and is usually expressed by the Coulomb equation.

T = C + Tan 0

Where C = cohesion

= normal stress on the shear plane

0 = angle of internal friction

The effective stress, ', is equal to the total stress 0 minus the porewater pressure u, i.e., ' = - U.

Several methods are available for determining the shear strength of materials. Those chosen for this study are:

1. Direct Shear Tests

   The direct shear test determines the shearing resistance across a predetermined failure plane. The rate of failure was chosen to permit full drainage and provide a measure of effective shear strength parameters.

2. Triaxial Tests

   Triaxial compression tests permit control of the minor principal stress or the confining pressure around a cylindrical specimen while the major principal stress is applied axially. The tests were performed under two conditions of drainage:

- Unconsolidated Undrained Tests (UU or Q)

  No drainage is permitted during application of the all-round or confining stress and no drainage is permitted during application of the deviator stress. Saturated samples were prepared and pore pressure measurements were made during the test. The unconfined compression test, Qu, is a special case of the UU test with the confining pressure equal to zero. This will be true only if menisci produce an effective confining pressure. The unconfined compression test is therefore normally applied to saturated, cohesive soils.

- Consolidated-Undrained Tests (CU or R)

  Drainage is permitted during application of the confining or normal load. The sample is consolidated with respect to the applied pressure, with drainage permitted. No drainage is permitted during the test, however pore pressures are measured.

The direct shear test was selected as a relatively straightforward test suitable for investigating the strength of both cohesionless soils and re-molded clays. It also provides a measure of the residual or ultimate strength parameters if any reduction in strength occurs after peak resistance has been developed.

The unconsolidated-undrained test with pore pressure measurements provides an assessment of the unconfined compression test. Because of the apparent cementation of samples of salt crystals when drying occurs the unconfined strength of salt samples should be dependent on the amount of drying and cementation permitted prior to testing and should not conform to the UU test in which saturation is maintained. For samples of saturated, cohesive soils the two methods (UU and Qu) should indicate the same undrained shear strength.

The consolidated-undrained test (CU or R) with pore pressure measurements is a relatively rapid test suitable to re-molded samples of cohesive or cohesionless soils. By measuring pore pressures during the test the results can be expressed in terms of effective stress.

The shear strength of cohesionless soils will depend on a number of factors. The factors which tend to influence strength significantly are the degree of density, void ratio or porosity, the shape of the grains and the gradation of the materials. In testing samples within this program an attempt was made to keep as many factors as possible constant in order to assess the effects of insolubles on the strength.

5.16.1 Direct Shear Tests

Samples were prepared by the static compaction method described previously. The nominal sample dimensions were 60 mm by 60 mm by 25 mm high.

For each mine and material type one test was conducted at each of four different normal stress levels as listed on Table 5.6. Samples were consolidated to the required normal stress in a single increment. Material A samples (insolubles) were immersed in water from the start of the consolidation while the other materials were immersed in brine. The coefficient of consolidation was determined from the records of vertical deflection vs. time.

Each sample was sheared at a controlled rate of displacement as given in Table 5.6. The rate of displacement was selected to ensure that failure occurred under drained conditions.

The magnitude, rate, and sequence of shearing cycles for each specimen is summarized in Table 5.6. At each normal load the specimen was sheared through a displacement of up to 7.6 mm to determine the peak shear stress required for failure. Following this the box was quickly cranked back to its original position by hand. Many of the specimens were cranked back and forth through several displacement cycles before the box was ultimately returned to its original position. The sample was then sheared at a controlled rate of shear through 1 or more cycles to determine the residual shear strength.

Table 3.6

Summary of Shearing Procedures Used in Direct Shear Tests

Mine	Material Type	Normal Stress (kPa)	Peak Cycle Displacement (mm)	Residual Cycles		Strain Rate (mm/min)	Comments
				No.	Total Displacement (mm)		
Cory	A	70	5.37	2	12.52	0.048	Cranked box back and forth 5 times by hand before each residual cycle
		150	7.59	2	13.09	0.048	
		400	7.13	1	4.92	0.048	
		800	5.36	2	12.13	0.048	
	B	65	6.41	2	13.66	0.081	Cranked box back and forth once by hand before each residual cycle
		143	6.08	2	11.43	0.081	
		438	6.33	2	13.08	0.081	
		810	5.85	2	11.31	0.081	
	C	65/143*	5.57	2+1*	11.94+5.40*	0.081	* Multi-stage Residual Cranked box back and forth 3 times by hand before each residual cycle
		143	6.56	2	10.95	0.081	
		438	5.86	2	11.26	0.081	
		810	6.19	2	11.77	0.081	
	D	65	6.03	2	11.17	0.081	Cranked box back and forth once by hand before each residual cycle
		143	6.14	2	11.42	0.081	
		438	4.27	2	12.44	0.081	
		810	5.38	3	15.52	0.081	
	E	72	7.03	1	5.01	0.048	Cranked box back by hand before each residual cycle
		148	8.46	1	7.26	0.048	
		448	7.85	1	7.25	0.048	
		784	6.71	1	6.97	0.048	
Rocanville	A	70	3.38	2	6.67	0.048	Cranked box back and forth 5 times by hand before each residual cycle
		150	3.82	2	11.89	0.048	
		450	6.67	2	9.31	0.048	
		800	5.10	2	9.37	0.048	
	B	65	6.39	2	12.36	0.081	Cranked box back and forth once by hand before each residual cycle
		143	6.24	2	11.30	0.081	
		438	5.69	2	11.60	0.081	
		810	5.28	2	9.95	0.081	
	C	65	6.64	2	11.56	0.183	Cranked box back and forth 3 times before each residual cycle * Multi-stage Residual
		143	6.93	2	10.82	0.183	
		438	6.14	2	10.69	0.183	
		438	5.78	1	6.00	0.081	
		158/438*	6.55	1+1*	6.15+6.82*	0.183	
		562	6.42	1	5.67	0.081	
	D	65	6.51	2	13.26	0.081	Cranked box back and forth once by hand before each residual cycle
		143	6.80	2	11.46	0.081	
		438	6.00	2	12.47	0.081	
		810	6.30	2	11.54	0.081	
	E	70	5.26	1	7.49	0.048	Cranked box back by hand before each residual cycle
		150	6.48	1	6.62	0.048	
		450	7.64	1	7.68	0.048	
		800	6.00	1	6.05	0.048	

Notes: * Multi-stage Test Procedure: Consolidate to one normal load, then shear for peak and residual cycles. Reconsolidate to a higher normal load and do another residual cycle.

Two multi-stage residual tests were carried out on Material C (one salt sample each from Cory and Rocanville). After the final residual cycle at the initial normal stress was completed, the normal stress was increased. The sample was allowed to consolidate under the new normal stress, and one additional shearing cycle was carried out.

The results of the direct shear testing are plotted on Figures 5.12 and 5.13. Detailed data on the tests is included in Appendix A.

The Cory samples show a definite correlation of strength parameters with salt and insoluble content. Samples containing salt contents of 80% or more exhibit much higher strength than the samples containing more than 30% insolubles or the pure insolubles. The samples containing 80% or more salt crystals appear to follow a curved peak failure envelope at low normal stress levels (up to 500 kPa) which then parallels the residual or ultimate failure envelope above approximately 500 kPa. This type of plot suggests possible degradation of the individual salt crystals. As expected, the lowest shear strength parameters are exhibited by the insoluble materials containing no salt crystals, with the measured parameters comparable to those typical of a surficial sandy clay in Saskatchewan. The highest strength parameters result from the addition of approximately 20% insolubles to salt crystals.

The Rocanville samples exhibited much the same trend. The curved peak failure envelope is somewhat less evident for the higher salt content and the tests on the salt tails produced very erratic results. The same basic trend is evident, however, with the addition of approximately 20% insolubles to salt tails resulting in the strongest material. Again the lowest shear strength parameters are produced by the insolubles containing no salt crystals.

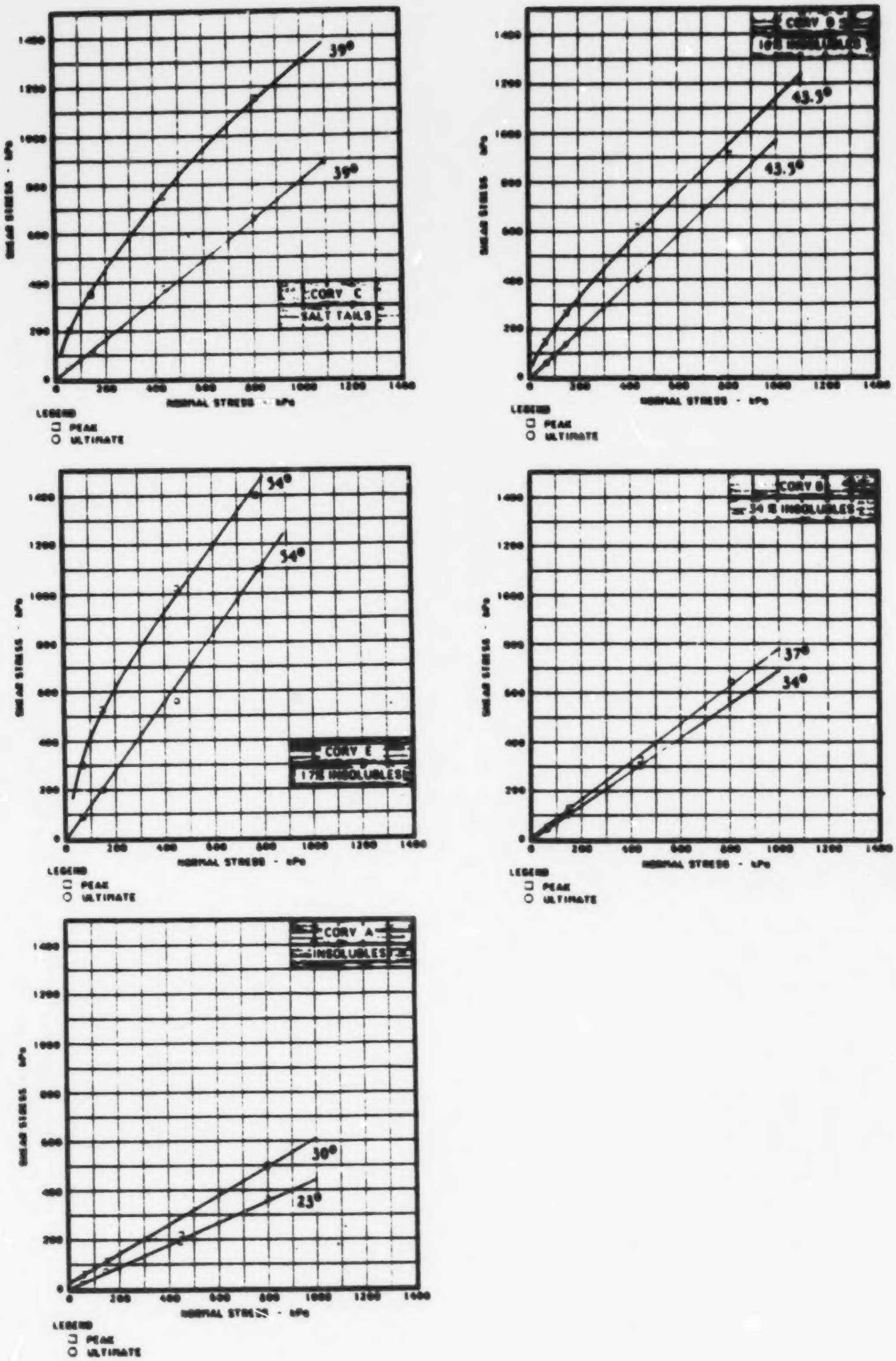


Figure 5.12

MOHR-COULOMB FAILURE ENVELOPES - DIRECT SHEAR TESTS
CORY MATERIALS

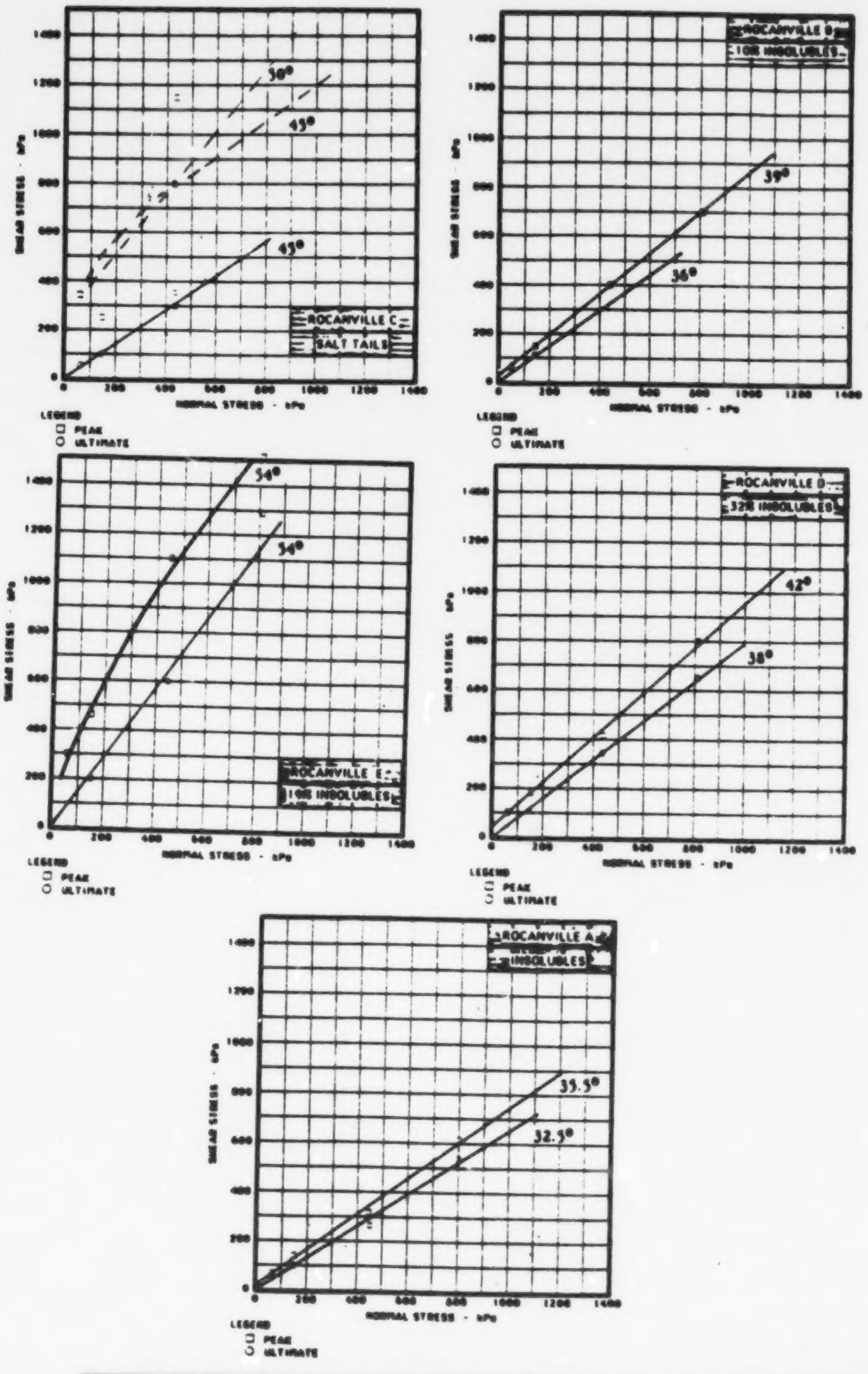


Figure 5.13

MOHR-COULOMB FAILURE ENVELOPES - DIRECT SHEAR TESTS
ROCANVILLE MATERIALS

In comparing the two sites, the Rocanville insolubles exhibit shear strength parameters slightly higher than the Cory samples. This is consistent with the lower clay content of the insolubles from Rocanville. The differences in shear strength of the salt tails from the two mines is much less pronounced.

5.16.2 Consolidated Drained Triaxial Tests - CU or R

Four specimens of each material type from each mine were prepared by static compaction methods. Samples were allowed to cure under room temperature and humidity conditions for 4 hours prior to mounting in the triaxial frame. Vertical filter paper strips were placed on the cylindrical surface of the specimens to accelerate drainage and equilibration of porewater pressures. Drainage and porewater pressure measurement from both ends of the sample were also provided for.

One or more rubber membranes were placed over the sample. Generally a single 0.30 mm thick latex rubber membrane was used. Because of the angular nature of salt crystals it was necessary to use 0.61 mm thick membranes with material C specimens, and at the highest confining pressure for material E specimens. Membrane puncture problems did occur on the Rocanville C (salt tails) sample at the highest confining pressure, and ultimately two 0.61 mm membranes were used.

Material A (insoluble) specimens were saturated with water, and water was used to fill the cell surrounding the specimen. For all other materials brine was used both within the sample and in the cell. The use of brine in the cell was considered necessary to prevent osmotic pressures from developing across the membrane. Initially isolation cells were installed on both the cell pressure and porewater pressure systems to prevent corrosive brine from entering the pressure measuring systems. It was however, determined that the compliance of the isolation cells was slowing the response time of the porewater pressure measuring system. Ultimately the isolation cell was removed from the porewater pressure measuring system and the system was thoroughly cleaned and flushed after the brine testing was completed.

Samples of material C were saturated by applying a differential porewater pressure across the sample, and allowing brine to flow into the bottom of the sample and out of the top until a steady, air-free flow was developed. Generally the samples took in about 16 ml of brine. Samples of materials A, B, D and E were saturated by applying a backpressure (i.e. equal cell and porewater pressures) of about 69 kPa (10 psi) and allowing the sample to reach equilibrium.

Following saturation, a backpressure of about 207 kPa was applied to the sample and a porewater pressure reaction test was carried out. If the results indicated that the sample was not sufficiently saturated, higher backpressures were applied until it was. In some cases, backpressures up to 621 kPa (90 psi) were required. Samples were then consolidated to the required effective confining pressure. The volume of water expelled from the sample with time was monitored, and these data were used to compute the coefficient of consolidation.

Four samples were tested for each material type at each mine. The samples were consolidated to the effective confining pressures listed in Table 5.7. They were then sheared at constant rates of strain (as given in Table 5.7). Failure, as defined by the maximum principal stress ratio, was attained for all specimens, except for the Rocanville material B specimen at a confining pressure of 454 kPa.

Table 5.7

Confining pressures and Strain Rates For Consolidated - Undrained Triaxial Tests

MATERIAL	EFFECTIVE CONFINING PRESSURES (kPa)	STRAIN RATE % PER HOUR
CORY A	70, 150, 450, 800	2.1 - 2.3
CORY B	72, 156, 444, 781	1.7 - 2.3
CORY C	71, 150, 483, 766	4.8 - 5.8
CORY D	72, 145, 448, 795	1.8 - 2.7
CORY E	87, 160, 450, 798	2.6
ROCANVILLE A	69, 150, 450, 800	2.1 - 2.2
ROCANVILLE B	69, 152, 454, 801	1.1 - 1.7
ROCANVILLE C	73, 149, 415, 709	5.1 - 5.3
ROCANVILLE D	83, 159, 462, 799	1.6 - 1.7
ROCANVILLE E	80, 161, 459, 794	2.3 - 2.4

The results of the consolidated drained triaxial tests are summarized in Figures 5.14 and 5.15. Detailed measurements of stress-strain and pore pressures are plotted in Appendix A.

The Cory materials indicate a correlation between strength parameters and the salt-insoluble content. The highest shear strengths are exhibited by salt tails containing 10% to 20% insolubles. Samples containing 80% or more salt crystals appear to follow a curved failure envelope at relatively low principal stresses. The measured effective stress parameters are consistent with those measured in the direct shear test. The lowest effective friction angle is exhibited by the insolubles (no salt crystals). The addition of up to 20% insolubles to the salt crystals increases the strength, although not in a dramatic fashion.

Rocanville samples exhibit much the same patterns although the results are not as consistent as Cory. The salt tails generate an apparent curvature in the failure envelope and test results are almost identical to Cory. The pure insolubles have the lowest strength and the strength parameters are very similar to the Cory insolubles. Results of tests performed on the salt tails containing approximately 10, 20 and 30% insolubles appear anomolous when compared to the Cory samples and the direct shear tests on Rocanville samples however, again, the addition of 20% insolubles to the salt tails appears to result in the highest strength parameters.

Test results for samples from the two sites seems to indicate similar strength parameters with Rocanville samples slightly stronger. The inconsistency in the results of tests on the Rocanville samples may lead to questions regarding the validity of sample preparation or test procedures in that case.

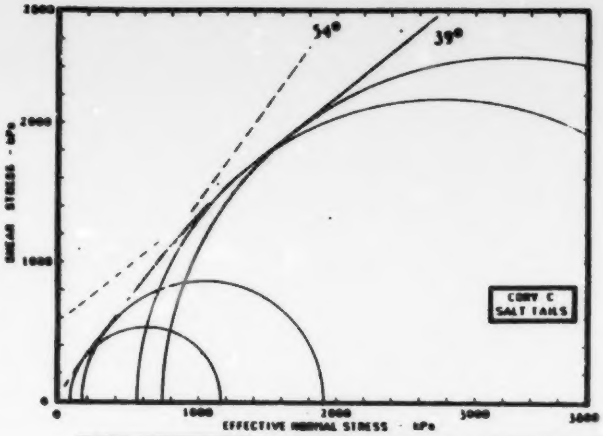


Figure A-3.8 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY C

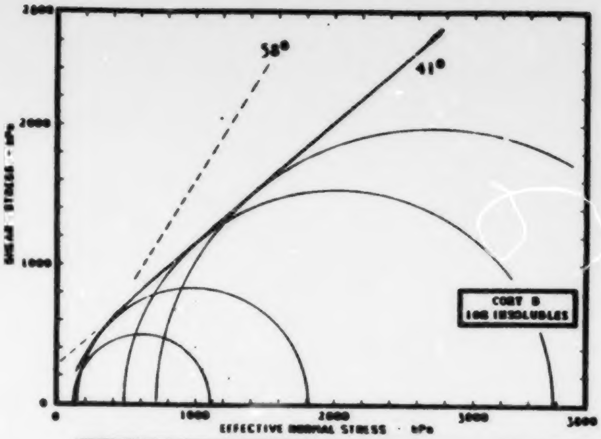


Figure A-3.9 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY D

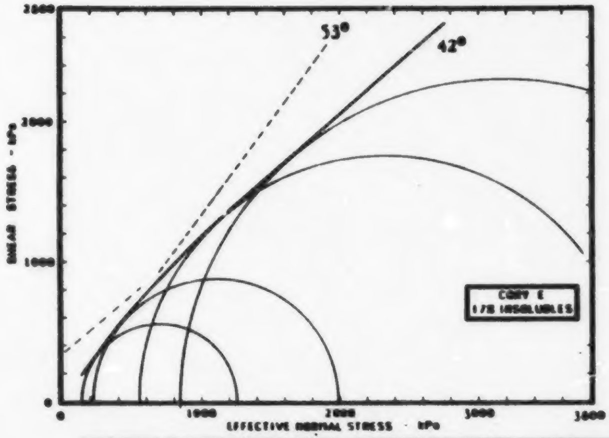


Figure A-3.10 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY E

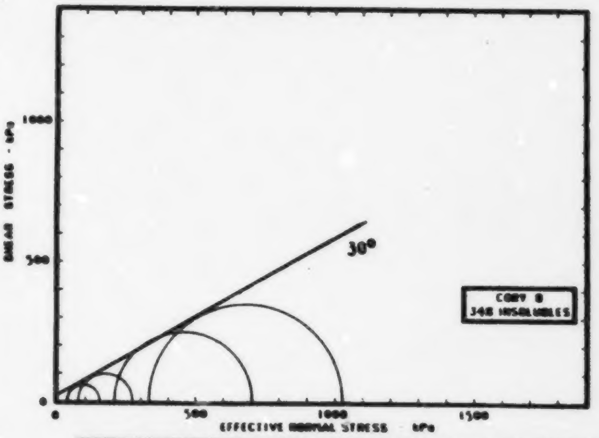


Figure A-3.7 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY B

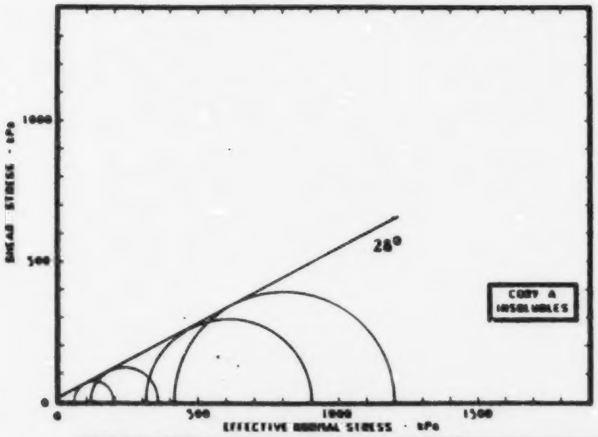


Figure A-3.6 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY A

Figure 5.14

MOHR-COULOMB FAILURE ENVELOPES - CU TRIAXIAL TEST
CORY MATERIALS

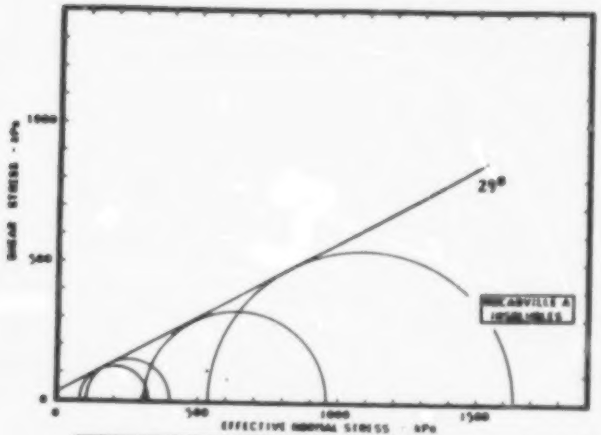


Figure B-3.1 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST ROCANVILLE A

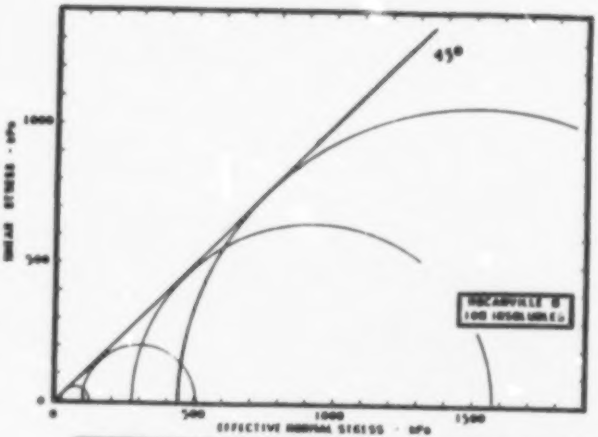


Figure B-3.2 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST ROCANVILLE B

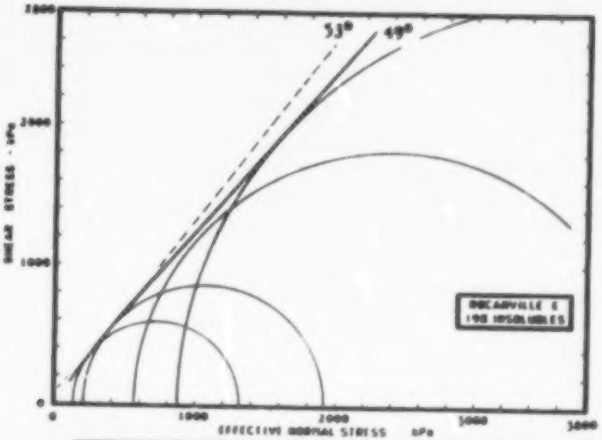


Figure B-3.5 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST ROCANVILLE E

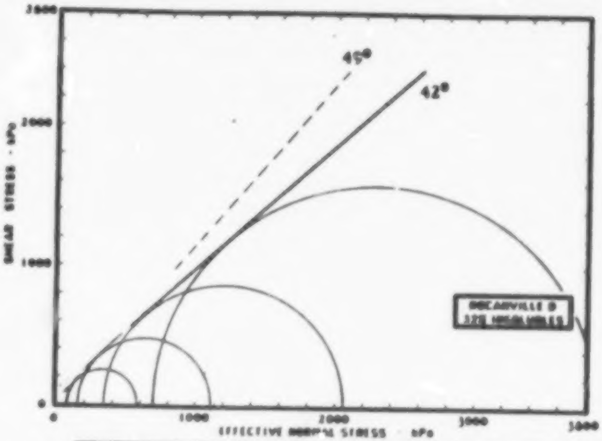


Figure B-3.4 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST ROCANVILLE D

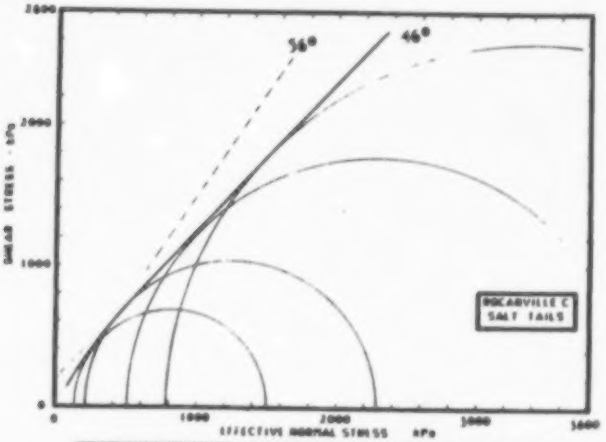


Figure B-3.3 MOHR COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST ROCANVILLE C

Figure 5.15

MOHR-COULOMB FAILURE ENVELOPES - CU TRIAXIAL TEST
ROCANVILLE MATERIALS

5.16.3 Unconsolidated Undrained Triaxial Tests (UU and Qu)

Specimens for unconsolidated undrained triaxial tests were prepared by curing, mounting and saturating in the same manner as the consolidated undrained test specimens. Backpressures between 207 kPa and 621 kPa were applied in the process of saturating the samples. Following this a porewater pressure reaction test was carried out. The cell pressure was increased and the increase in porewater pressures was noted. The resultant porewater pressures are listed in Table 5.8. The porewater pressure response was generally not one hundred percent, thus slight effective confining pressures were generated, as recorded in Table 5.8. In the case of specimens of material A, this effective confining pressure was eliminated before shearing began; for the other materials it was not. No drainage from the samples were allowed and pore pressures were measured during the test.

The samples were sheared to failure at the controlled rates of strain listed in Table 5.8.

Table 5.8

Confining Pressures, Porewater Pressures, and Strain Rates for Unconsolidated-Undrained Triaxial Tests

MATERIAL	EFFECTIVE CONFINING PRESSURE (kPa)	POREWATER PRESSURE (kPa)	STRAIN RATE (mm/min)
CORY A	0	495	0.038
CORY B	35	681	0.030
CORY C	28	1023	0.081
CORY D	3	1107	0.055
CORY E	2	907	0.027
ROCANVILLE A	0	498	0.038
ROCANVILLE B	85	948	0.018
ROCANVILLE C	16	1034	0.081
ROCANVILLE D	2	904	0.036
ROCANVILLE E	4	915	0.036

Specimens for unconfined compression testing were prepared in the manner previously described. Two samples were prepared for each material type from each mine, except that four Rocanville material C samples (salt tails) were prepared. After being removed from the mold, each sample containing salt tails was allowed to cure under room temperature and humidity conditions for a period of 4 hours. An additional two samples of salt tails from Rocanville were allowed to cure for 24 hours and 72 hours to confirm the effects of curing time.

Samples were mounted in a compression frame and loaded to failure at a constant rate of displacement of 1.22 mm per minute. The vertical stress on the sample was recorded at regular displacement intervals throughout each test.

Detailed test results for the tests are given in Appendix A. These results are summarized in Table 5.9. With the exception of pure insoluble samples no correlation is evident between the saturated, confined UU test and the unconfined test. It is evident that the strength measured in the unconfined test on samples containing salt tails is entirely dependent on the amount of drying and subsequent re-crystallization of salt which results in "cementation" of the sample. This increase in strength with drying would increase at a decreasing rate until it becomes constant. The unconfined strength will be a function of the initial density and amount of drying permitted and becomes a measure of the cohesion available due to cementing of the salt crystals.

Table 5.9

Results of Unconsolidated- Undrained Triaxial and Unconfined Compression Tests

		UNCONFINED		UU TRIAXIAL
MATERIAL	INITIAL DENSITY (kg/m³)	CURING TIME (hours)	MAXIMUM DEVIATOR STRESS (kPa)	DEVIATOR STRESS AT MAXIMUM STRESS RATIO (kPa)
CORY				
C(salt tails)	1540	4	500	430
		4	480	
D(10%insols)	1580	4	210	160
		4	225	
E(17%insols)	1800	4	373	150
		4	490	
		4	420	
B(34%insols)	1650	4	164	80
		4	195	
A(insols)	1650	-	195	180
		-	200	
ROCANVILLE				
C(salt tails)	1600	4	210	360
		4	250	
		24	355	
		72	550	
B(10%insols)	1480	4	93	220
		4	90	
E(19%insols)	1800	4	270	90
		4	260	
D(32%insols)	1850	4	225	100
		4	220	
A(insols)	1700	-	240	180
		-	23	

6.0 DISCUSSION

The mineralogy and chemical composition of the tailings were confirmed to be in accordance with expectations. The constituents present conform to the analysis of the raw ore body, however, the relative proportions of the insoluble constituents present seem to fluctuate. In particular the proportion of clay particles present in the the insolubles appears to vary with time. This could result in a variation of the mineralogy of deposits within the waste management scheme. This study was, of necessity, restricted to the materials as produced in the mill and did not consider the effects of possible segregation of mineral constituents within the tails pile and settlement ponds after slurrying on the tails pile.

In testing the materials some basic properties are fundamental to engineering analysis. These include grain size and grain size distribution, index properties and specific gravity of the particles. This study was successful in defining some of these, however, it also identified numerous shortcomings in attempting to apply standard soil mechanics test procedures to soluble materials, i.e. NaCl.

The grain size was analyzed using standard mechanical dry sieving techniques and by indirect hydrometer methods. These were successful with the mineral samples however, difficulties were evident when the techniques were applied to samples containing soluble salts. Dry sieving of salt crystals by mechanical means involves drying which results in some cementation or bonding of the salt crystals. Subsequent breaking up of these clusters to duplicate the original grain size distribution is very subjective and an alternate method of determining grain size must be developed. Attempts to develop alternate methods of wet sieving were attempted unsuccessfully in this study but we are optimistic that these do hold promise and can be successful. Analyzing grain size by hydrometer methods was completely unsuccessful for samples containing salt tails.

The grain size distribution determined for the materials are consistent with previous studies, indicating that the salt tails are uniformly graded, corresponding to a coarse grained sand size and the insoluble wastes contain fine grained silt to clay sizes.

The specific gravity of solid particles is a fundamental property that is required in routine engineering calculations. The determinations of specific gravity yielded some unexpected results particularly in respect to the salt crystals. The value of 2.10 to 2.14 measured is somewhat below what would be expected from the limited literature available. Further testing is required to assess this property and its variations.

The Atterberg Limits are a standard measure in analysis of soils and can normally be related to other engineering properties. The results of this study indicate that the insolubles exhibit medium to high plasticity when tested outside of a salt environment. The tests involving mixtures of mineral particles and salt crystals indicate that in the order of 25% more insolubles must be added to salt crystals to obtain a material which exhibits cohesion and plasticity. This is in contrast to what would be expected for sand of equivalent gradation and indicates that an analogy of salt crystals to sand may not be applicable.

The expression of water content poses a problem when brine is used as the mixing fluid. Determination of water content in the normal fashion, by drying, results in significant crystallization of salt from solution and at higher brine contents and has a significant effect on the calculation. In order to more accurately reflect the water to solids ratio of the wet material, it was concluded that the water content determinations must be corrected to account for dissolved salt. Correcting the water content to remove the effects of re-crystallization leads to a correction also being applied to measurements of density.

The moisture-density relationships of soils were used to determine the water content of the soil which will enable the lowest void ratio to be achieved with a given amount of compactive effort. It can often be related to the plasticity characteristics of a soil. This test was used to provide a standard relationship for use in preparation of samples and provide a consistent benchmark for the various tests. The test results are comparable to results that would be expected for sandy clay soils or in the case of salt tails, clean sands. Definitive moisture density relationships were developed for all samples tested. For a given compactive effort as defined by ASTM B-698 (Standard Proctor Compactions Test) it was found that the maximum dry density (or lowest void ratio) can be achieved by combining approximately 20 to 30% insolubles with salt crystals.

The permeability of a material is of fundamental importance when the material is to be subjected to increased loading. The time required for drainage will govern the pore pressure build-up and effective resisting strength available. The permeability tests confirm the expected, i.e. the salt tailings are relatively free draining and the insolubles are very impermeable or slow draining. The addition of insolubles to salt tailings results in a relatively constant rate of decrease in permeability up to an insoluble content of 40 to 60%, beyond which the change in permeability is minimal. This suggests a threshold value much higher than would be expected for sand-clay mixtures. The permeability of salt tails is expected to be somewhat dependent on consolidation pressure and the possible changes in grain size of salt crystals subjected to high stresses over an extended period of time, however, investigation of this was beyond the scope of this study. The changes in permeability of the salt tails following long term, high stresses may be very significant in terms of pore pressure build-up and dissipation and consequently, overall stability of the tails pile.

The consolidation characteristics were investigated using a relatively rapid test in an attempt to minimize the effects of creep or visco plastic behaviour of the salt crystals. In general the samples containing greater than approximately 30% insolubles and the samples of insoluble materials exhibited classical consolidation characteristics applied to soil mechanics. The samples of salt tails and samples of low insoluble content (less than 20%) exhibited some characteristics similar to granular soils, however, in general are difficult to interpret. Pore pressures appear to dissipate rapidly, however, the possible rearrangement of the grains of salt under stress cannot be accurately assessed. It would thus appear, from this preliminary data, that dissipation of pore pressures may not be a concern for salt tailings containing up to 20% insolubles, but is probably a major concern for engineering analyses of salt tailings containing grater than 20% insolubles and is definitely a concern for insolubles containing little or no salt crystals.

The shear strength parameters were investigated using direct shear and triaxial cells. The unconsolidated undrained triaxial test (UU test with pore pressure measurements) and the special case of the UU test, the unconfined compression test, provided little useful data on strength properties. It does however, illustrate the considerable amount of strength available to salt tails from cementation or re-crystallization of salt during evaporation or drying. This cementation phenomena is well illustrated by the unconfined test, however, the tests also confirm that, when dealing with samples containing salt tails, the unconfined compression test results cannot be related to the theory applied to cohesive soils in classical soil mechanics.

The direct shear tests and consolidated drained triaxial tests provided excellent data on the strength properties of the different materials and the changes in shear strength resulting from a combination of salt tails and insoluble mineral soils.

Two categories of shear strength parameters may be postulated for the materials studied, i.e.:

- Those applicable to salt tails and samples of salt tails containing less than 20% insolubles by dry weight.
- Those applicable to insolubles and samples of salt tails containing more than 30% insolubles by dry weight.

Materials made up of greater than 30% insolubles exhibit straight line Mohr-Coulomb failure envelopes typical of mineral soils. Materials containing less than 20% insolubles yield a curved peak failure envelope at low stresses and a straight line envelope parallel to the residual or ultimate envelope above principal stresses of approximately 500 kPa. This non-linear failure envelope is very similar to the results of direct shear tests performed by Golder Associates (1978) on samples obtained from the tails pile at the Cory mine. In their tests on salt tailings sampled at Rocanville the University of Saskatchewan (1982) proposed a straight line envelope with no curvature. However, the curvature seems very clearly defined from the tests performed herein and is considered quite definitive. This non-linear relationship may be a result of re-arrangement or degradation of salt tails.

The non-linear failure envelope may be very significant in the analysis of the stability of tails pile. The conventional approach of approximating the failure envelope with a linear Mohr-Coulomb relationship could lead to a calculated factor of safety greater than the actual factor of safety. This is illustrated by a comparison of the curved failure envelope with the straight line approximation used by the University of Saskatchewan (Pufahl and Yosheda, 1982). It is possible that use of the shear strength parameters indicated by the straight line approximation could lead to serious over-estimates of the factor of safety and it would therefore be prudent to develop techniques of stability analyses using the non-linear failure envelopes. Further testing is required to clearly define the failure envelopes.

The relative strengths of the materials are also very revealing. As expected the insolubles have the lowest strengths is terms of the effective angle of shearing resistance. The highest strengths are, however, achieved by the addition of approximately 20% insolubles to the salt tails. The strength of salt tails alone falls somewhere between the two.

In general and particularly for samples from the Cory minesite, the samples containing less than 30% insolubles exhibited a tendency to dilate when failed. This is typical of a dense, granular material.

In terms of absolute strengths all materials exhibit relatively high effective angles of internal friction. The insolubles, with an effective friction angle of approximately 30° compare favourably with the glacial deposits forming the foundation materials for the tails piles. Typical glacial tills at the Saskatchewan minesites have maximum effective internal friction angles of approximately 30-35° while typical alluvial and lacustrine silts have maximum effective internal friction angles of approximately 22 to 30°. The build-up of excess pore pressures during rapid loading and the expected slow dissipation of these pore pressures would be of concern for materials containing greater than 20% insolubles.

The effective angles of internal friction were investigated over confining pressures ranging from approximately 70 to 800 kPa. The 800 kPa maximum is a direct result of equipment limitations. The maximum normal stress of 800 kPa corresponds to a tailings pile height of approximately 50 m. It is possible that further reductions in the effective angle of internal friction will occur at higher confining pressures, however, further testing is required to define this.

7.0 CONCLUSIONS

A number of conclusions drawn from the study have been discussed. The major general conclusions may be summarized as follows:

- Published literature related to the engineering properties of potash tailings generated by potash mines in Saskatchewan is extremely limited and the understanding of properties required to perform effective analyses and design does not seem to exist. The state-of-the-art knowledge must be expanded to permit complete engineering evaluations.
- The insoluble mineral constituents found in potash tailings are consistent, however, the proportion of each mineral varies between ore bodies and to a lesser extent within each ore body.
- Many of the testing procedures used in standard soil mechanics have to be modified greatly in their application to materials containing soluble minerals such as halite. The need for development and refinement of testing techniques becomes apparent. This results from both their solubility and the plastic or visco plastic flow of these minerals, in particular the rate-, temperature-, and history-dependent deformation characteristics.
- The engineering properties of the insoluble mineral tailings with no salt present can be determined by classical soil mechanics techniques. The materials classify and exhibit properties typical of a silty clay of medium to high plasticity. The materials exhibit a reasonably high shear strength (effective angle of internal friction approximately 30°) and a low permeability (k approximately 10^{-7} cm/sec) classifying as practically impervious. Drainage from the materials is very slow and excess pore pressures generated by loading would be slow to dissipate.

- The engineering properties of the halite tailings (in the virtual absence of insolubles) are more difficult to determine and are more unique. The material in an uncemented state appears to have a grain size distribution similar to coarse sands. The strength parameters appear significantly non-linear with the Mohr-Coulomb failure envelope is typically curved at lower stresses tending to an angle parallel to the residual or ultimate effective angle of internal friction. The measured strength is relatively high with peak effective friction angles in excess of 40°. The permeability is relatively high and generally the salt tails classify as a free draining material. Plastic or visco plastic creep under sustained loading is known to occur, however, the implications of this behaviour were not defined.

- When soluble salt tailings and insoluble mineral tailings are combined, the properties appear to be dominated by salt tails for insoluble contents of 20% or less and appear to be dominated by the insolubles for insoluble contents of 30% or more.
- Maximum shear strength is achieved when the insoluble content of the tailings is approximately 20%.
- Maximum densities (minimum void ratios) for a given compactive effort are achieved when the insoluble content is approximately 20% to 30%.
- Permeability of the combined materials is significantly lower for higher clay contents, with drainage changing from good to poor at insoluble contents of approximately 20%.
- There appears to be an optimum insoluble content of tailings at which maximum strength can be combined with desirable drainage characteristics. Adding 10% insolubles to salt tails increases strength slightly while adding 20% increases strength significantly and appears to maximize available strength. Insoluble contents above approximately 25% to reduce the available strength of the tailings significantly. If slimes were stored separately and leaching of the salt occurred, the available strength (and stability) would be reduced.
- Segregation, either intentional or unintentional, of the constituents in a tailings pile will have a significant effect on the stability of the pile.

- It must be concluded that considerable effort is required in the following areas:
  - further definition of the engineering properties of the tailings and in particular the shear strength parameters and pore fluid pressures applicable to stability analyses
  - the time and history-deformation characteristics of the salt tails must be evaluated along with the implications of this mechanism in respect to permeability and shear strength.
  - definition of the distribution of the constituents within and beneath the existing tailings piles
  - optional placement procedures to optimize the materials properties

8.0 CLOSURE

The study undertaken and reported herein was of necessity limited in scope. It has however, provided some baseline data to further the state-of-the-art knowledge of the physical properties of potash tailings. The study has accomplished a major objective, by providing a logical basis for the problems to be addressed and for further efforts to be optimized.

REFERENCES

See Appendix B for Selected References

APPENDIX A

LABORATORY TEST DATA

PCS Mining

A subsidiary of the Potash Corporation of Saskatchewan

APPENDIX A
SECTION 1

CONSOLIDATION TEST DATA

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : CORY MINES
SAMPLE : A
DATE (D/M/Y) :21/07/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.48 INS.
AREA OF SAMPLE = 2.99 SQINS.
WEIGHT OF SOLIDS = 40.20 GMS.
SPECIFIC GRAVITY = 2.78

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4750	0.1796	0.6082		
15.20	0.2487	0.4737	0.1783	0.6038	4.50	0.0011
30.40	0.2433	0.4683	0.1729	0.5855	3.50	0.0014
60.80	0.2359	0.4609	0.1655	0.5605	3.60	0.0013
121.60	0.2279	0.4529	0.1575	0.5334	1.75	0.0027
243.20	0.2191	0.4441	0.1487	0.5036	1.50	0.0030
486.40	0.2094	0.4344	0.1390	0.4707	2.00	0.0022
972.80	0.1957	0.4207	0.1253	0.4244	2.00	0.0020
1945.60	0.1787	0.4037	0.1083	0.3668	1.25	0.0030
3891.30	0.1603	0.3853	0.0899	0.3045	1.25	0.0027

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

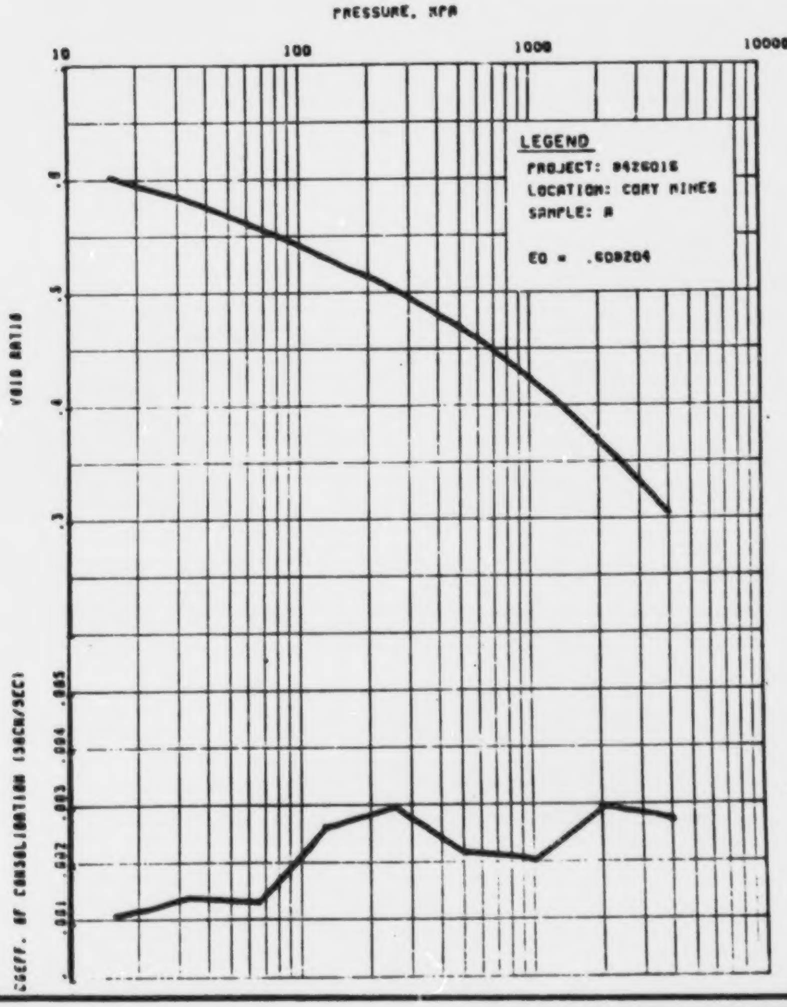


Figure A-1.1

CONSOLIDATION TEST RESULTS
CORY A - INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : CORY MINES
SAMPLE : B
DATE (D/M/Y) :21/07/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 2.98 SQINS.
WEIGHT OF SOLIDS = 38.44 GMS.
SPECIFIC GRAVITY = 2.21

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4874	0.1317	0.3702		
15.20	0.2466	0.4840	0.1283	0.3607	3.50	0.0015
30.40	0.2421	0.4795	0.1238	0.3480	3.50	0.0015
60.80	0.2353	0.4727	0.1170	0.3289	3.00	0.0017
121.60	0.2248	0.4622	0.1065	0.2994	2.60	0.0019
243.20	0.2143	0.4517	0.0960	0.2699	3.00	0.0015
486.40	0.1998	0.4372	0.0815	0.2291	4.20	0.0010
972.80	0.1843	0.4217	0.0660	0.1855	2.00	0.0020
1945.60	0.1672	0.4046	0.0489	0.1374	6.00	0.0006
3891.30	0.1570	0.3944	0.0387	0.1088	9.00	0.0004

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

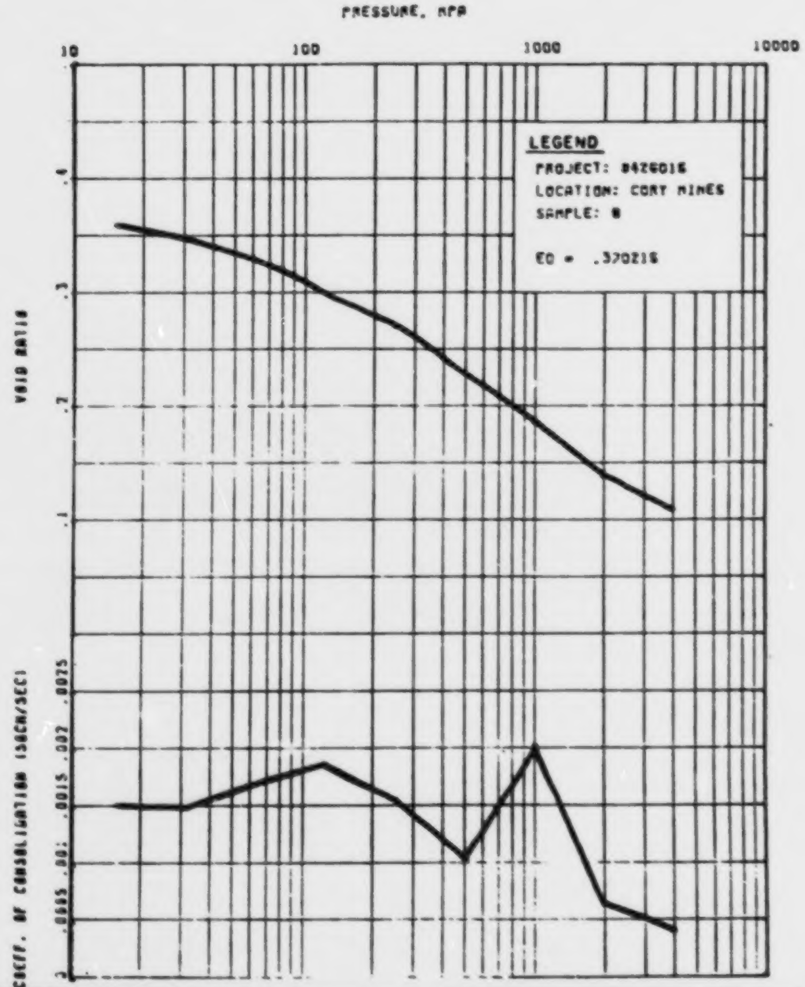


Figure A-1.2

CONSOLIDATION TEST RESULTS
CORY B - 34 % INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : CORY MINES
SAMPLE : C
DATE (D/M/Y) :20/07/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.50 INS.
AREA OF SAMPLE = 2.99 SQINS.
WEIGHT OF SOLIDS = 38.44 GMS.
SPECIFIC GRAVITY = 2.10

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.5005	0.1266	0.3387		
15.20	0.2492	0.4997	0.1258	0.3365		
30.40	0.2424	0.4929	0.1190	0.3183	0.17	0.0326
45.60	0.2329	0.4834	0.1095	0.2929	0.33	0.0161
60.80	0.2316	0.4821	0.1082	0.2894	0.33	0.0161
121.60	0.2270	0.4775	0.1036	0.2771	0.33	0.0157
243.20	0.2225	0.4730	0.0991	0.2651	0.83	0.0061
729.60	0.2123	0.4628	0.0889	0.2378	1.50	0.0033
1702.40	0.2055	0.4560	0.0821	0.2196	1.00	0.0047
3648.10	0.1978	0.4483	0.0744	0.1990	1.00	0.0046

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

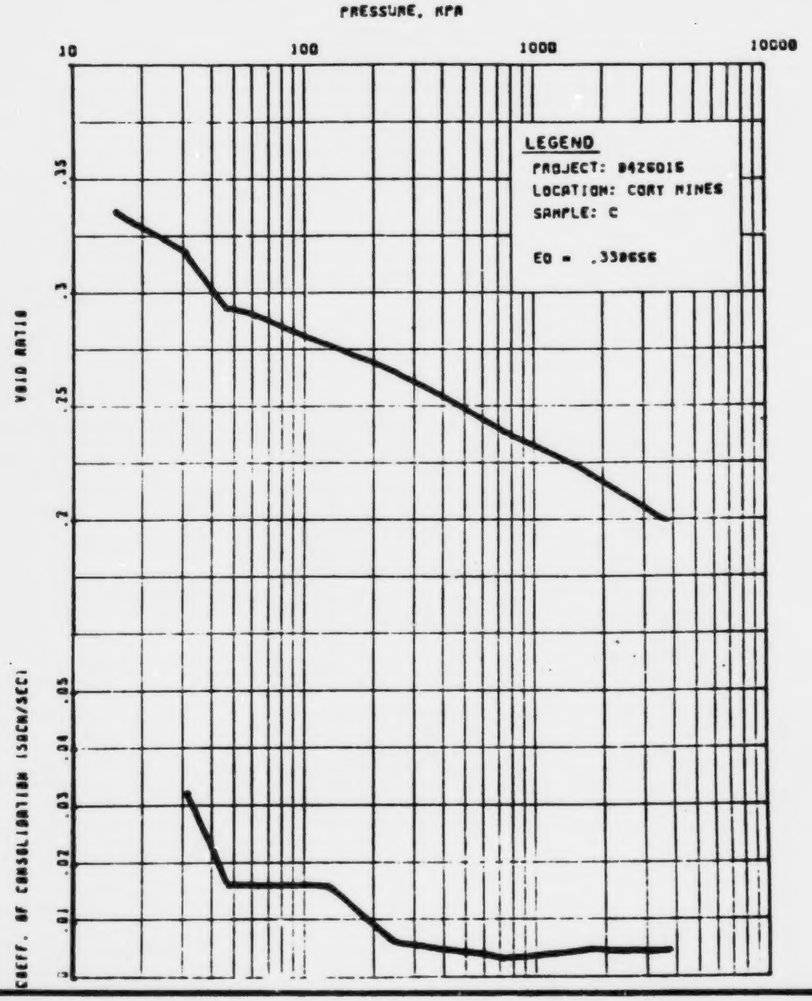


Figure A-1.3

CONSOLIDATION TEST RESULTS
CORY C - SALT TAILS

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : CORY MINES
SAMPLE : MATERIAL D
DATE (D/M/Y) :08/08/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.50 INS.
AREA OF SAMPLE = 2.99 SQINS.
WEIGHT OF SOLIDS = 35.62 GMS.
SPECIFIC GRAVITY = 2.17

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.5000	0.1653	0.4940		
15.20	0.2404	0.4904	0.1557	0.4654	1.25	0.0044
30.40	0.2371	0.4871	0.1524	0.4555	1.30	0.0042
60.80	0.2332	0.4832	0.1485	0.4438	12.00	0.0004
121.60	0.2277	0.4777	0.1430	0.4274	5.00	0.0010
243.20	0.2188	0.4688	0.1341	0.4008	3.10	0.0016
486.40	0.2141	0.4641	0.1294	0.3868	3.50	0.0014
972.80	0.2071	0.4571	0.1224	0.3659	2.50	0.0019
1945.60	0.1982	0.4482	0.1135	0.3393	1.50	0.0031
3891.30	0.1943	0.4443	0.1096	0.3276	9.00	0.0005

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

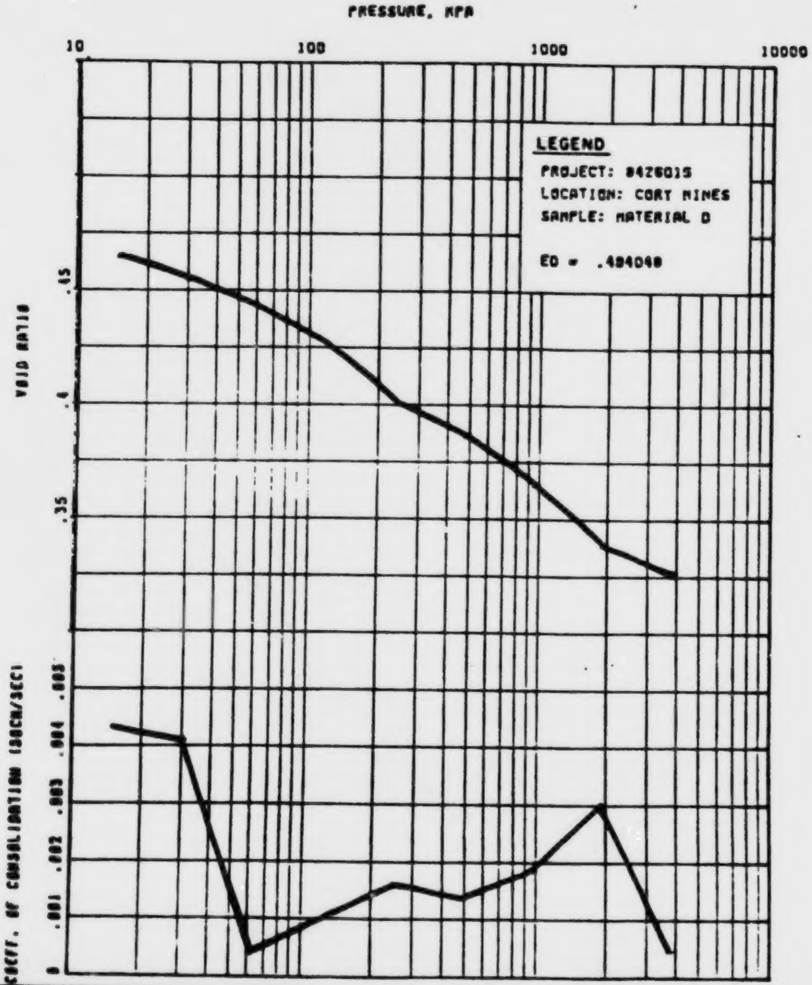


Figure A-1.4

CONSOLIDATION TEST RESULTS
CORY D - 10 % INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : CORY MINES
SAMPLE : MATERIAL E
DATE (D/M/Y) :08/08/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 3.00 SQINS.
WEIGHT OF SOLIDS = 39.70 GMS.
SPECIFIC GRAVITY = 2.25

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4860	0.1263	0.3512		
15.20	0.2452	0.4812	0.1215	0.3378	1.50	0.0035
30.40	0.2415	0.4775	0.1178	0.3276	3.00	0.0017
60.80	0.2365	0.4725	0.1128	0.3137	2.00	0.0025
121.60	0.2313	0.4673	0.1076	0.2992	2.50	0.0020
243.20	0.2224	0.4584	0.0987	0.2745	3.00	0.0016
486.40	0.2177	0.4537	0.0940	0.2614	3.50	0.0013
972.80	0.2110	0.4470	0.0873	0.2428	9.00	0.0005
1945.60	0.2032	0.4392	0.0795	0.2211	5.00	0.0009
3891.30	0.1833	0.4193	0.0596	0.1658	2.40	0.0017

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

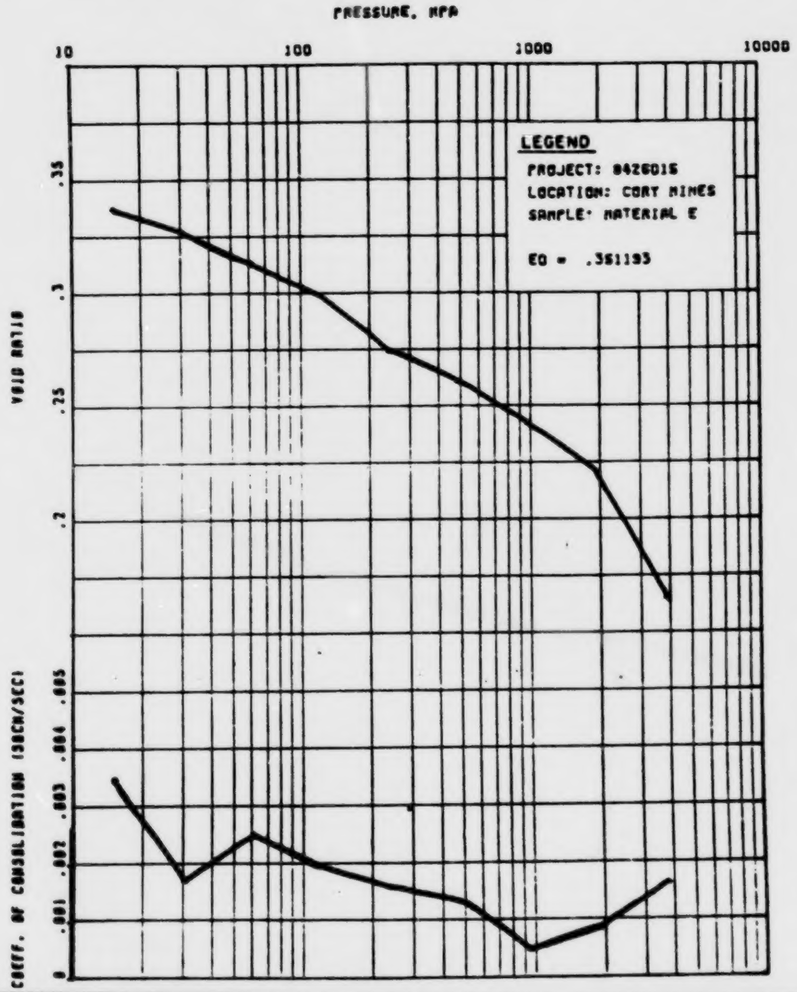


Figure A-1.5

CONSOLIDATION TEST RESULTS
CORY E - 17 % INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : ROCANVILLE
SAMPLE : A
DATE (D/M/Y) :21/07/84

DIAMETER SAMPLE = 1.99 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 3.09 SQINS.
WEIGHT OF SOLIDS = 42.98 GMS.
SPECIFIC GRAVITY = 2.78

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4900	0.1853	0.6079		
15.20	0.2499	0.4899	0.1852	0.6076		
30.40	0.2499	0.4899	0.1852	0.6076		
60.80	0.2467	0.4867	0.1820	0.5971	1.50	0.0036
121.60	0.2414	0.4814	0.1767	0.5797	1.00	0.0053
243.20	0.2358	0.4758	0.1711	0.5613	1.50	0.0034
486.40	0.2297	0.4697	0.1650	0.5413	1.50	0.0034
972.80	0.2231	0.4631	0.1584	0.5196	1.25	0.0039
1945.60	0.2158	0.4558	0.1511	0.4957	1.50	0.0032
3891.30	0.2024	0.4424	0.1377	0.4517	1.25	0.0036

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

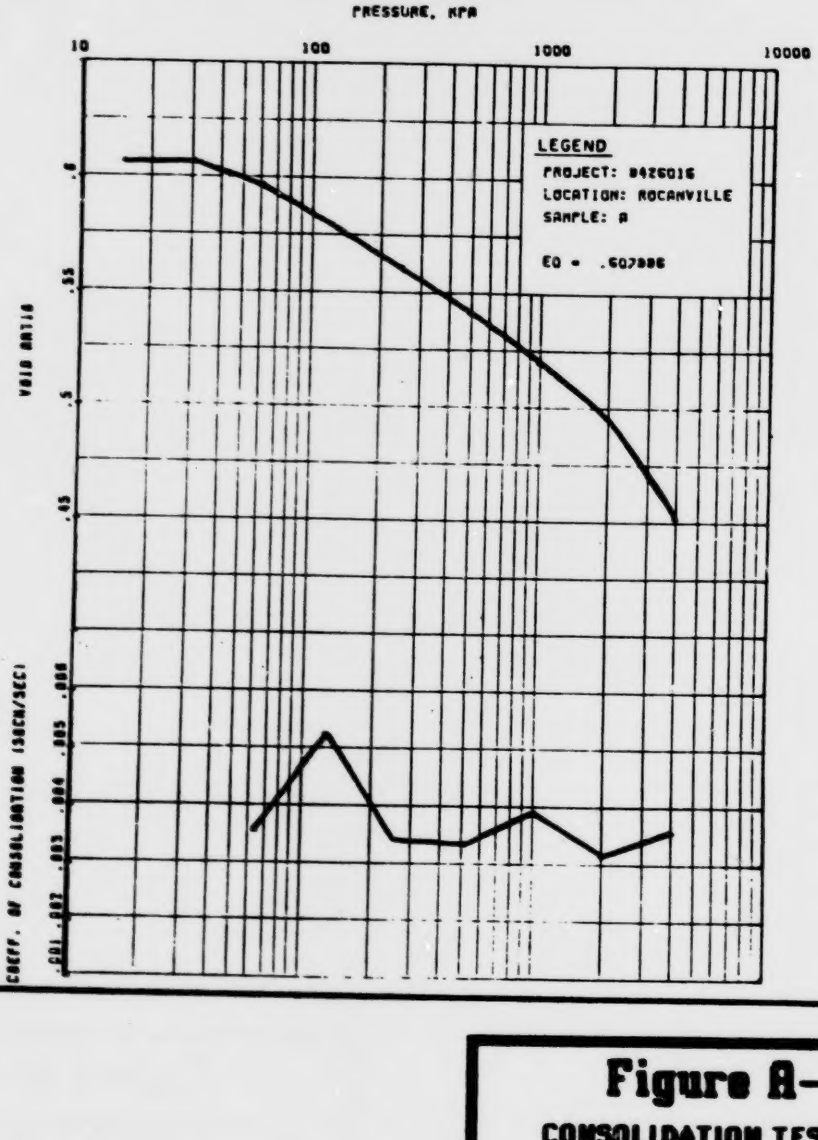


Figure A-1.6

CONSOLIDATION TEST RESULTS
ROCANVILLE A - INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : ROCANVILLE
SAMPLE : B
DATE (D/M/Y) :21/07/84

DIAMETER SAMPLE = 1.97 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 3.05 SQINS.
WEIGHT OF SOLIDS = 34.01 GMS.
SPECIFIC GRAVITY = 2.56

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4902	0.2245	0.8447		
15.20	0.2331	0.4733	0.2076	0.7811		
30.40	0.2221	0.4623	0.1966	0.7397		
60.80	0.2106	0.4508	0.1851	0.6964	0.75	0.0062
121.60	0.2010	0.4412	0.1755	0.6603	1.50	0.0030
243.20	0.1886	0.4288	0.1631	0.6136	1.00	0.0042
486.40	0.1793	0.4195	0.1538	0.5786	2.30	0.0017
972.80	0.1690	0.4092	0.1435	0.5399	2.50	0.0015
1945.60	0.1569	0.3971	0.1314	0.4943	2.25	0.0016
3891.30	0.1369	0.3771	0.1114	0.4191	2.25	0.0014

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

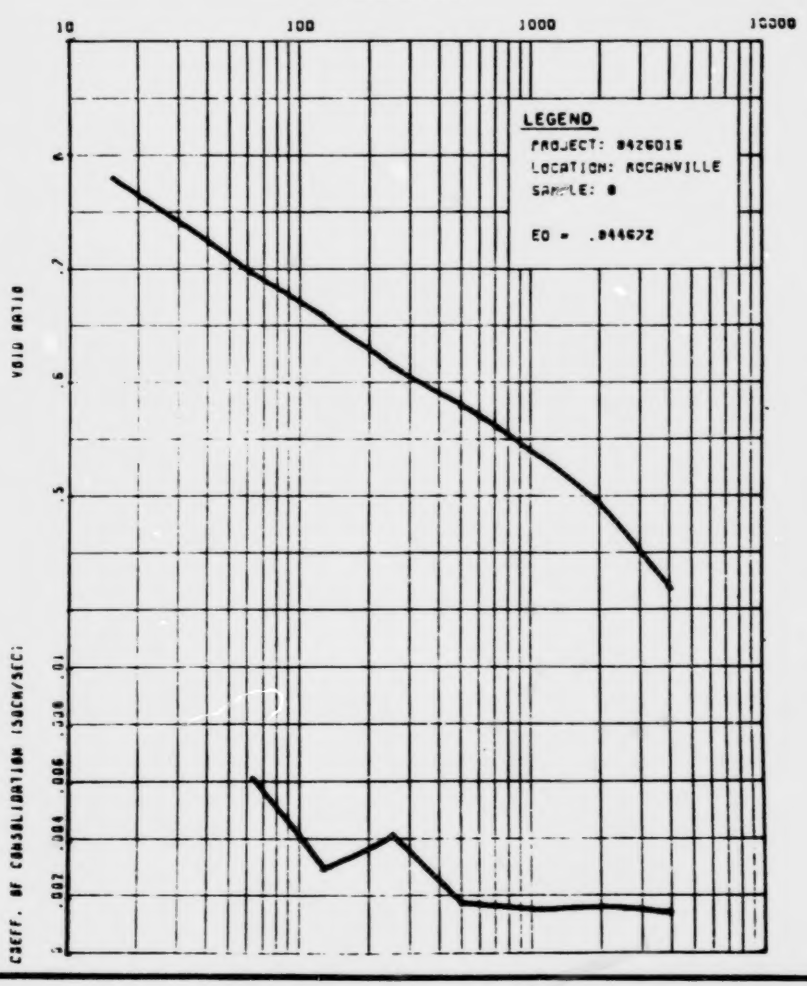


Figure A-1.7

CONSOLIDATION TEST RESULTS
ROCANVILLE B - 10% INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : ROCANVILLE
SAMPLE : C
DATE (D/M/Y) :21/10/84

DIAMETER SAMPLE = 1.95 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 2.99 SQINS.
WEIGHT OF SOLIDS = 38.38 GMS.
SPECIFIC GRAVITY = 2.10

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4921	0.1192	0.3196		
15.20	0.2500	0.4921	0.1192	0.3196		
30.40	0.2468	0.4889	0.1160	0.3110		
60.80	0.2377	0.4798	0.1069	0.2866	4.00	0.0013
121.60	0.2311	0.4732	0.1003	0.2689	3.00	0.0017
243.20	0.2245	0.4666	0.0937	0.2512	1.70	0.0029
486.40	0.2215	0.4636	0.0907	0.2432	1.00	0.0049
972.80	0.2163	0.4584	0.0855	0.2292	1.10	0.0044
1945.60	0.2100	0.4521	0.0792	0.2123	1.90	0.0025

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

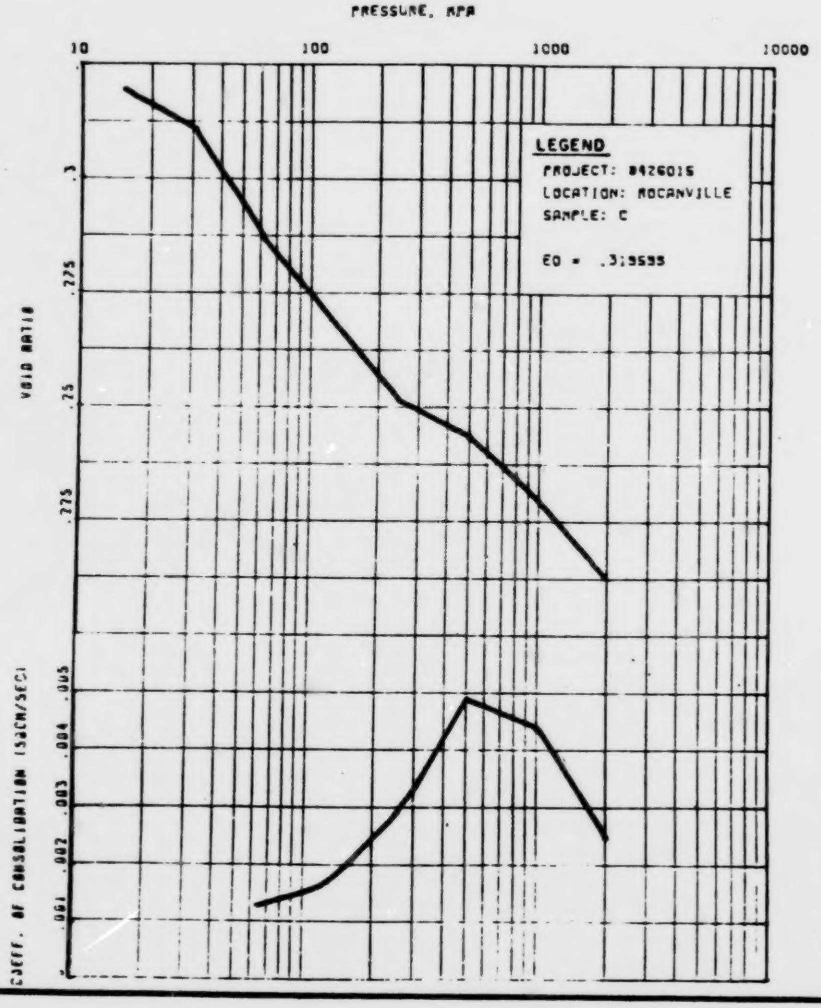


Figure A-1.8

CONSOLIDATION TEST RESULTS
ROCANVILLE C - SALT TAILS

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : ROCANVILLE MINES
SAMPLE : MATERIAL D
DATE (D/M/Y) :08/08/84

DIAMETER SAMPLE = 1.97 INS.
HEIGHT OF SAMPLE = 0.49 INS.
AREA OF SAMPLE = 3.05 SQINS.
WEIGHT OF SOLIDS = 42.70 GMS.
SPECIFIC GRAVITY = 2.35

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2HO (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4920	0.1284	0.3530		
15.20	0.2443	0.4863	0.1227	0.3373	1.50	0.0036
30.40	0.2416	0.4836	0.1200	0.3299	1.30	0.0041
60.80	0.2377	0.4797	0.1161	0.3192	3.50	0.0015
121.60	0.2327	0.4747	0.1111	0.3054	3.50	0.0015
243.20	0.2261	0.4681	0.1045	0.2873	5.00	0.0010
486.40	0.2200	0.4620	0.0984	0.2705	2.60	0.0019
972.80	0.2129	0.4549	0.0913	0.2510	8.00	0.0006
1945.60	0.2038	0.4458	0.0822	0.2259	6.00	0.0008
3891.30	0.1924	0.4344	0.0708	0.1946	2.50	0.0017

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

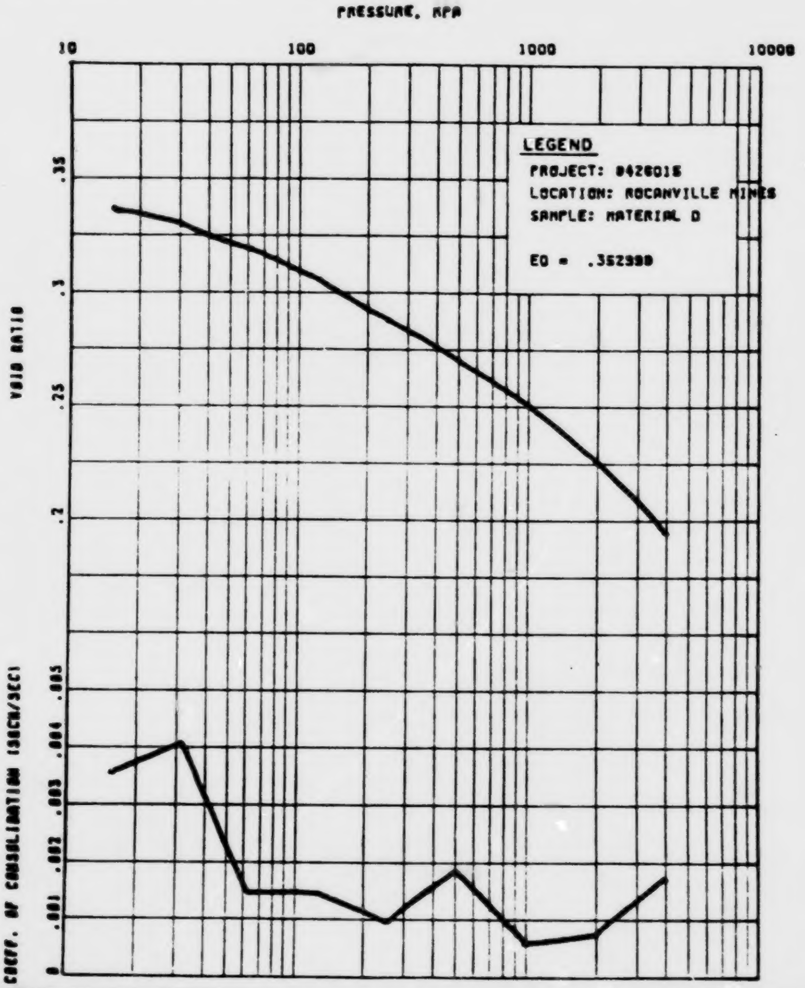


Figure A-1.9

CONSOLIDATION TEST RESULTS
ROCANVILLE D - 32% INSOLUBLES

CONSOLIDATION TEST

PROJECT: 8426015
LOCATION : ROCANVILLE MINES
SAMPLE : MATERIAL E
DATE (D/M/Y) :08/08/84

DIAMETER SAMPLE = 1.99 INS.
HEIGHT OF SAMPLE = 0.48 INS.
AREA OF SAMPLE = 3.10 SQINS.
WEIGHT OF SOLIDS = 40.62 GMS.
SPECIFIC GRAVITY = 2.24

STRESS (KPA)	DIAL (INS)	2H (INS)	2H-2H0 (INS)	VOID RATIO	T90 (MIN)	CV (SQCM/SEC)
0.00	0.2500	0.4800	0.1230	0.3445		
15.20	0.2464	0.4764	0.1194	0.3344	2.00	0.0026
30.40	0.2431	0.4731	0.1161	0.3252	6.50	0.0008
60.80	0.2396	0.4696	0.1126	0.3154	5.00	0.0010
121.60	0.2356	0.4656	0.1086	0.3042	9.00	0.0005
243.20	0.2268	0.4568	0.0998	0.2795	2.75	0.0017
486.40	0.2233	0.4533	0.0963	0.2697	4.00	0.0012
972.80	0.2182	0.4482	0.0912	0.2554	2.00	0.0023
1945.60	0.2116	0.4416	0.0846	0.2370	10.00	0.0004
3891.30	0.1953	0.4253	0.0683	0.1913	5.50	0.0007

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

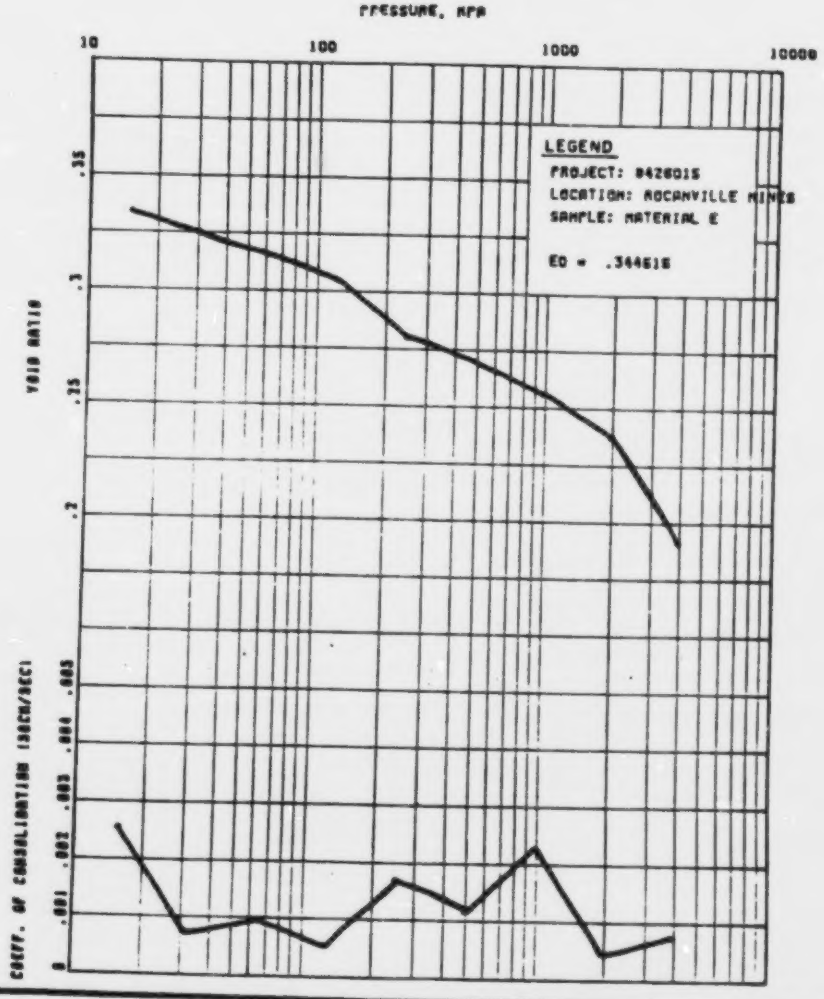


Figure A-1.10

CONSOLIDATION TEST RESULTS
ROCANVILLE E - 19 % INSOLUBLES

APPENDIX A
SECTION 2

DIRECT SHEAR TEST DATA

MOHR-COULOMB
FAILURE ENVELOPES
Direct Shear Tests

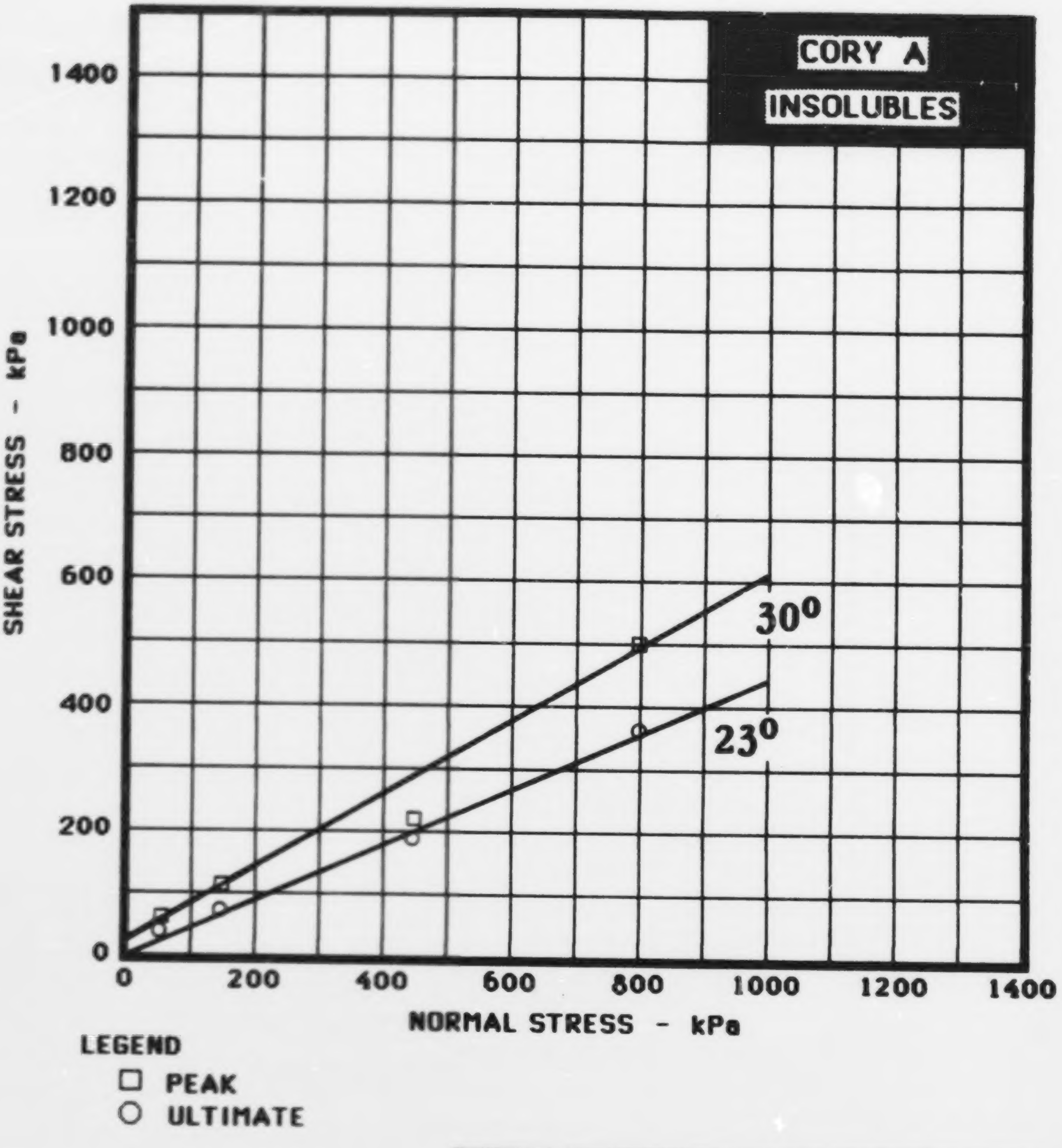


Figure A-2.1

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
CORY A - INSOLUBLES

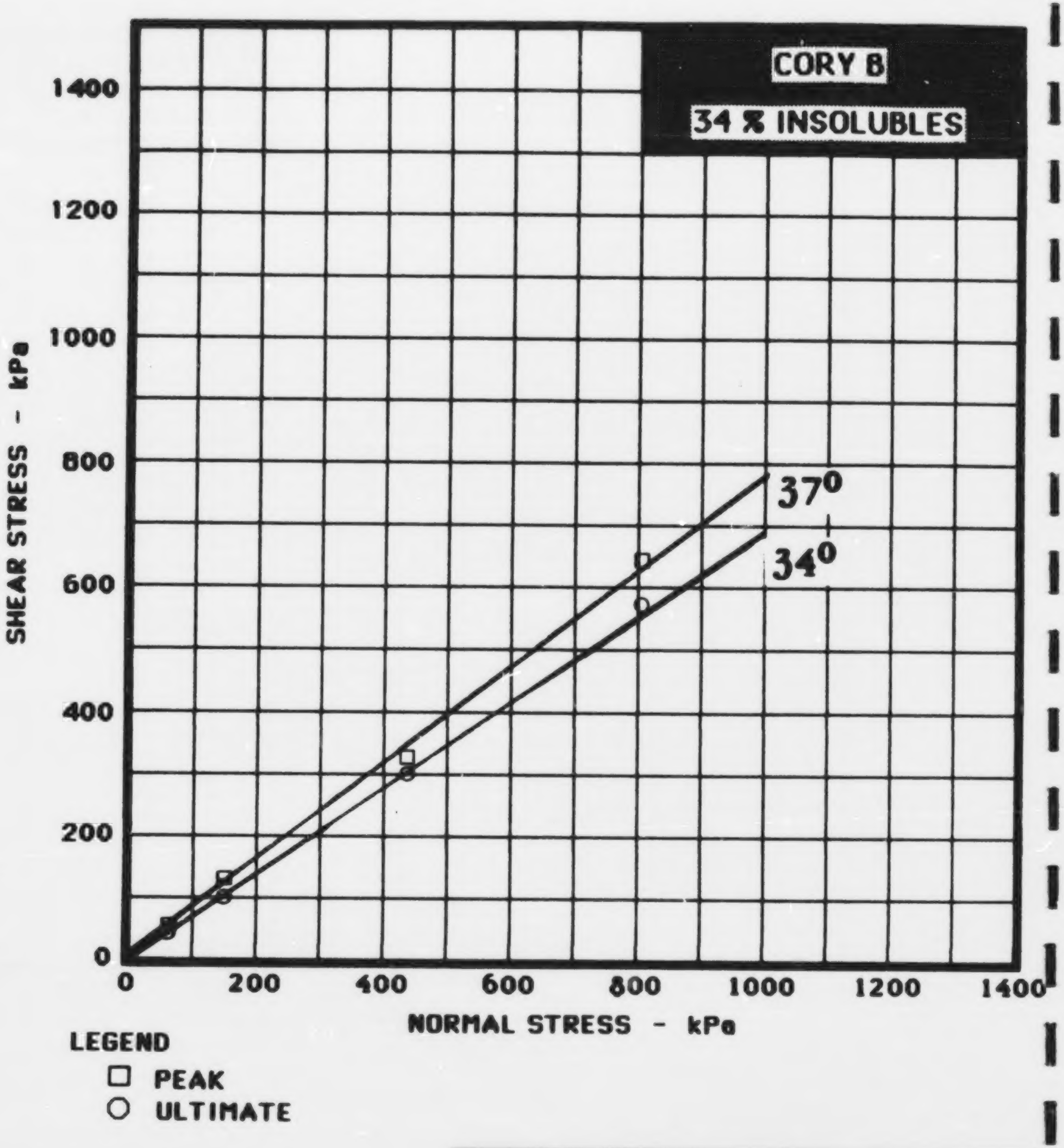


Figure A-2.2

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
CORY 8 - 34 % INSOLUBLES

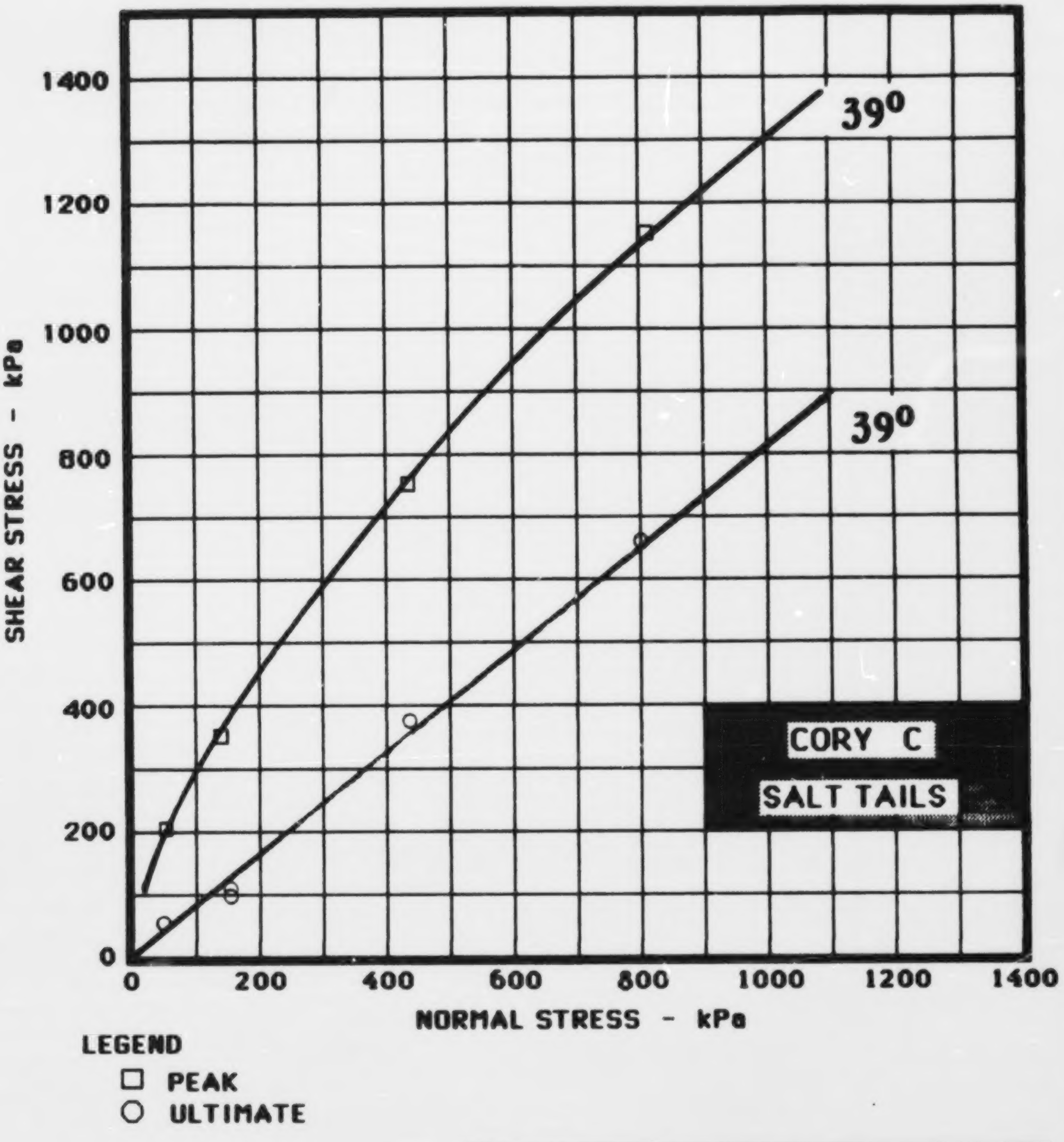


Figure A-2.3

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
CORY C - SALT TAILS

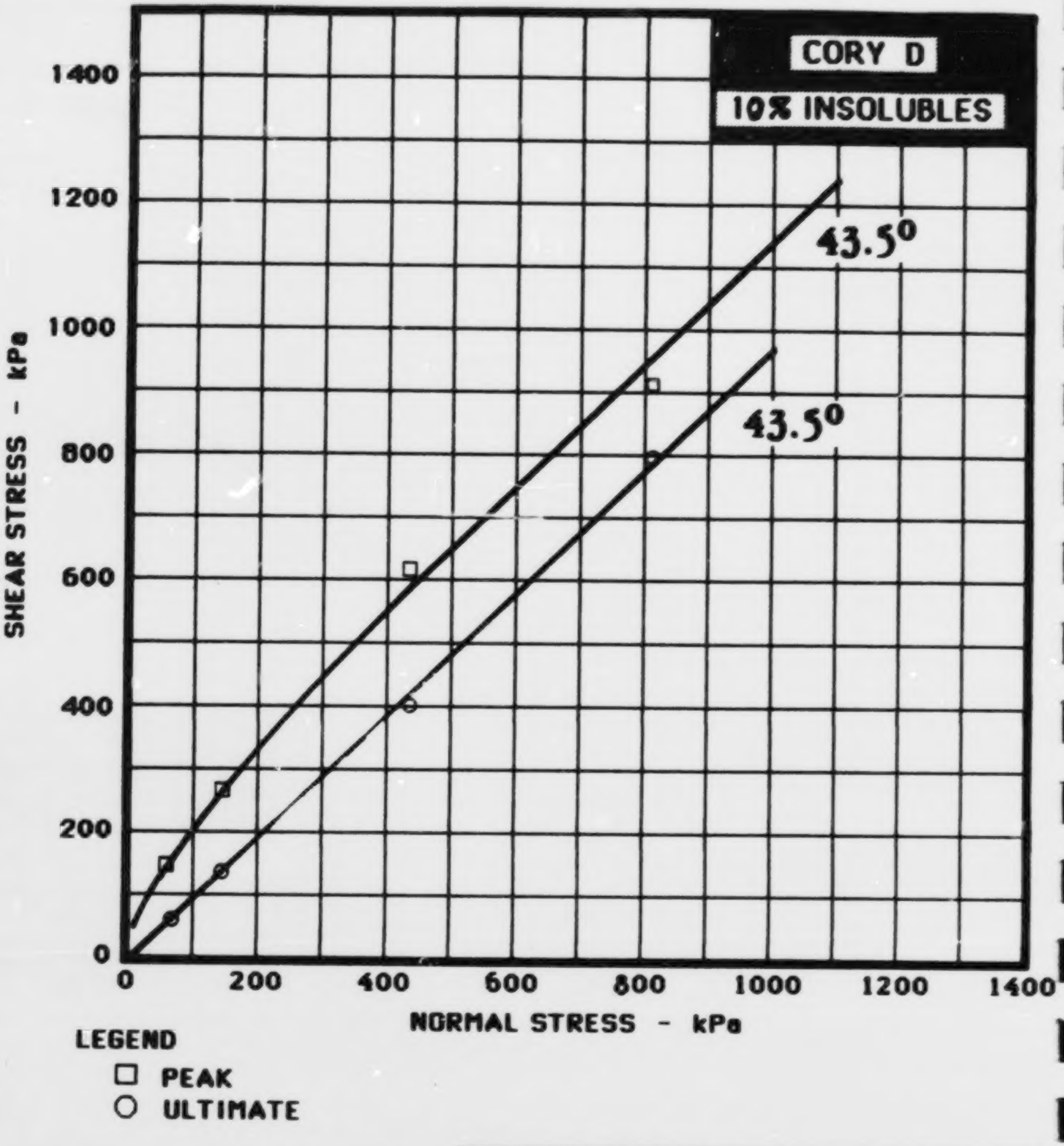


Figure A-2.4

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
CORY D - 10% INSOLUBLES

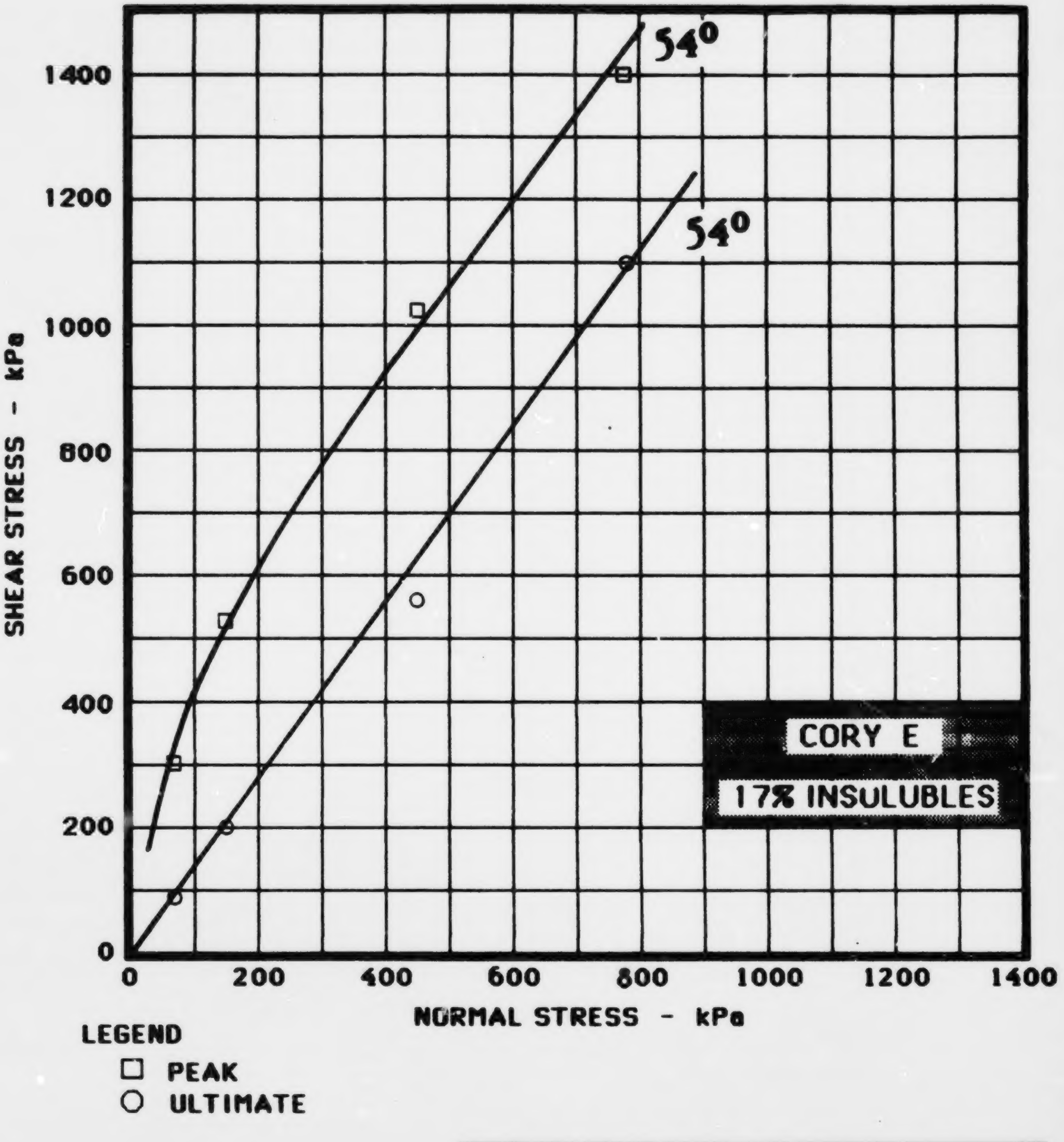


Figure A-2.5

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
CORY E - 17% INSOLUBLES

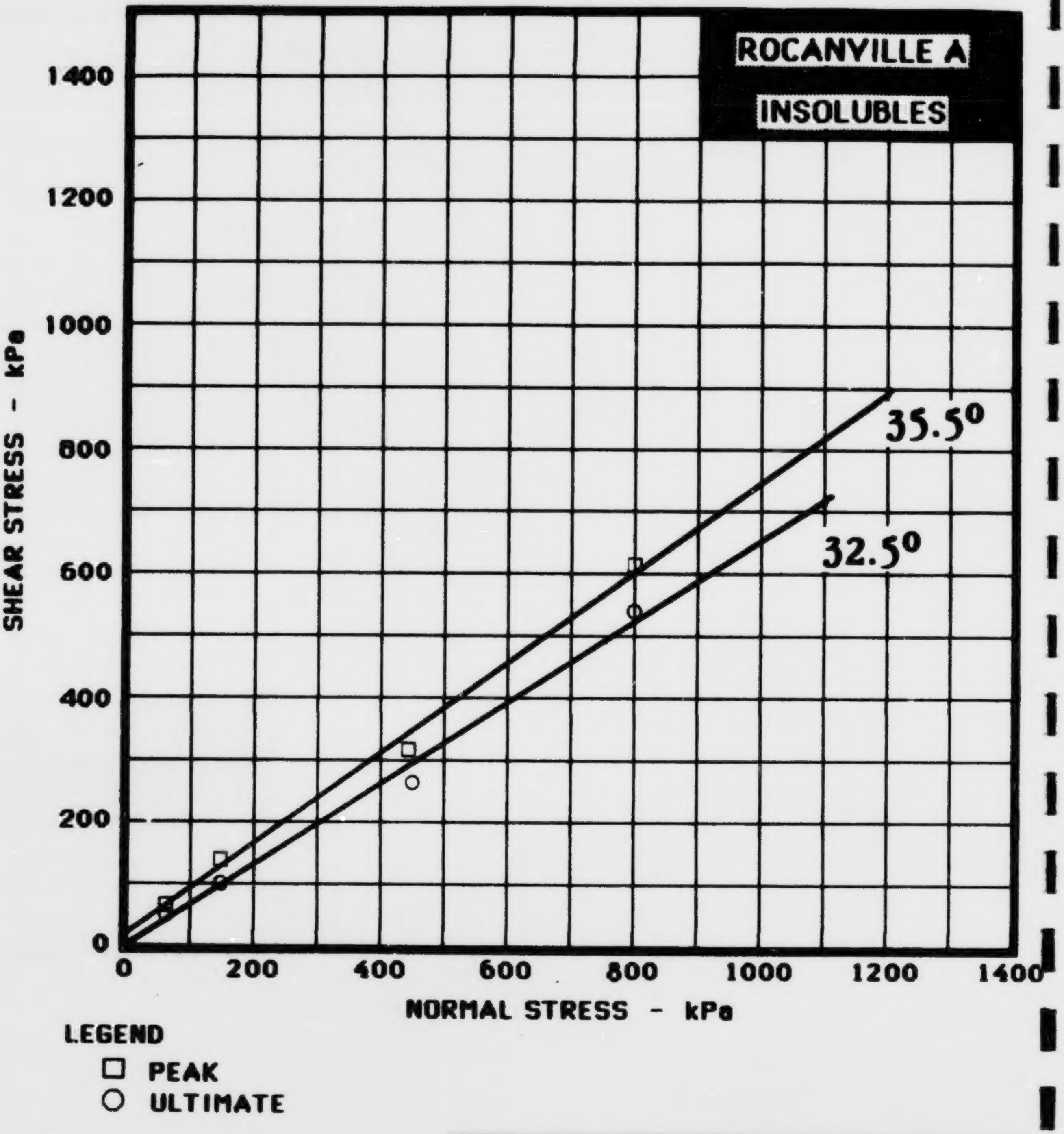


Figure A-2.6

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
ROCANVILLE A - INSOLUBLES

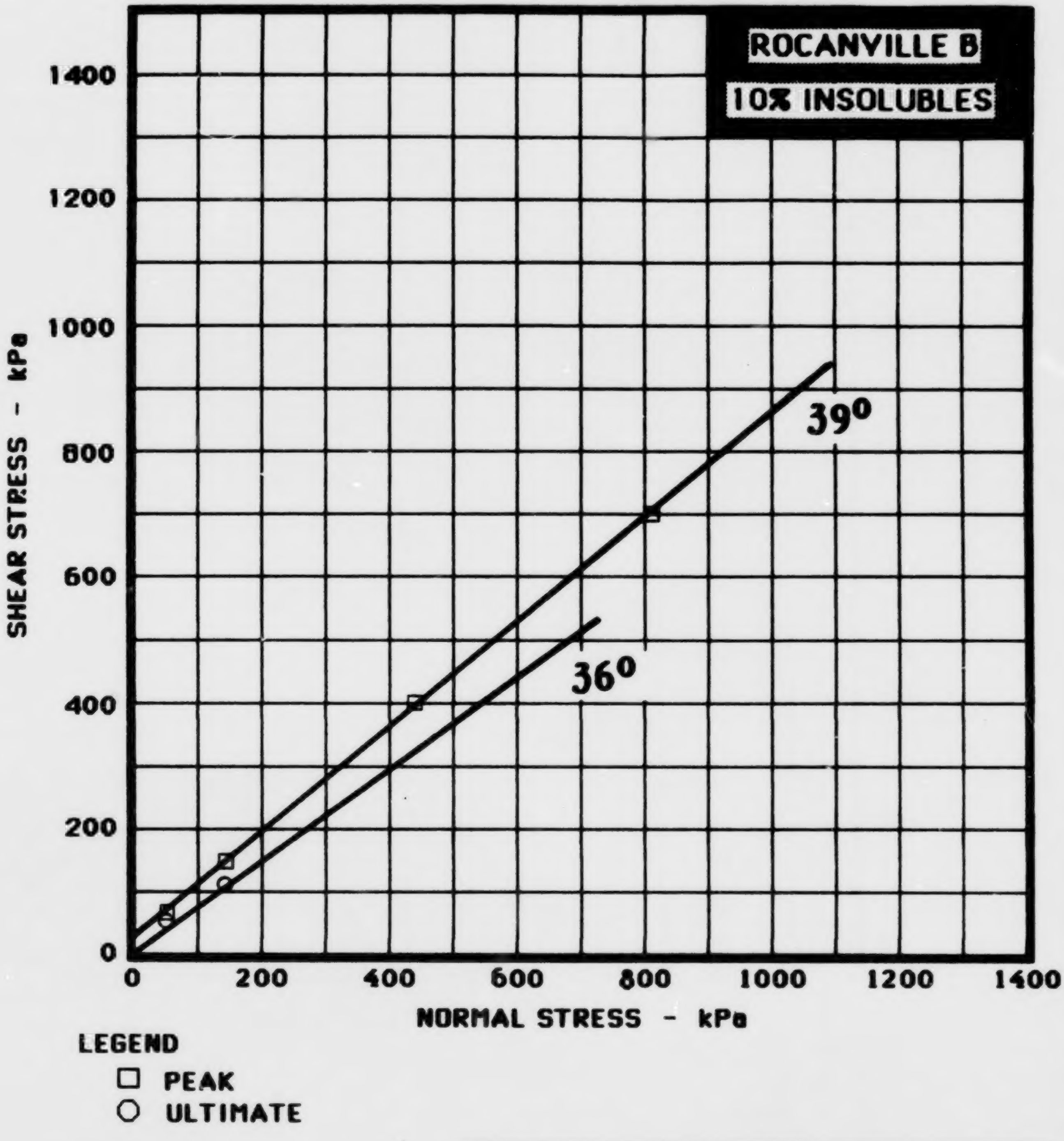


Figure B-2.7

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
ROCANVILLE B - 10% INSOLUBLES

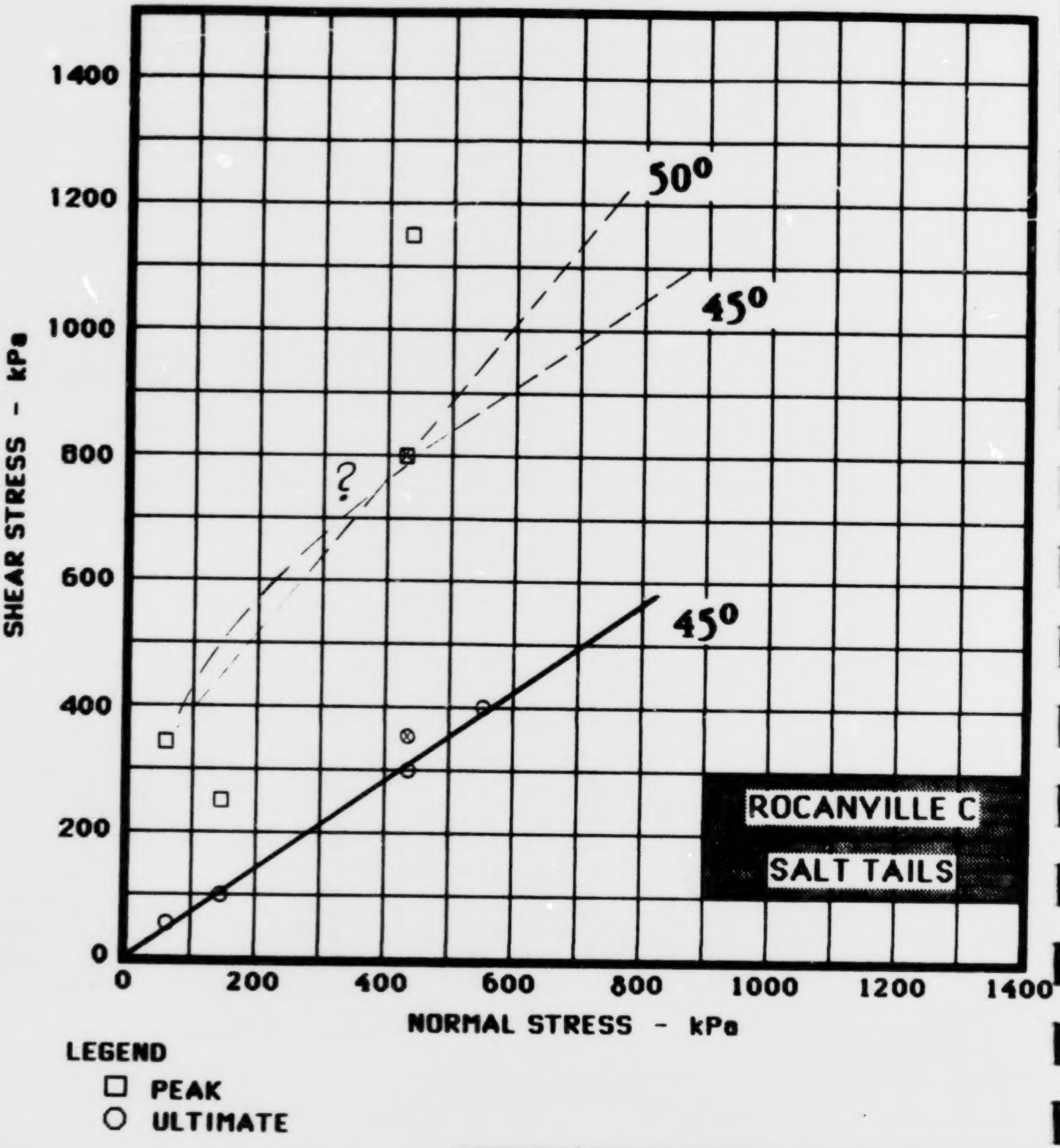


Figure A-2.8

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
ROCANVILLE C - SALT TAILS

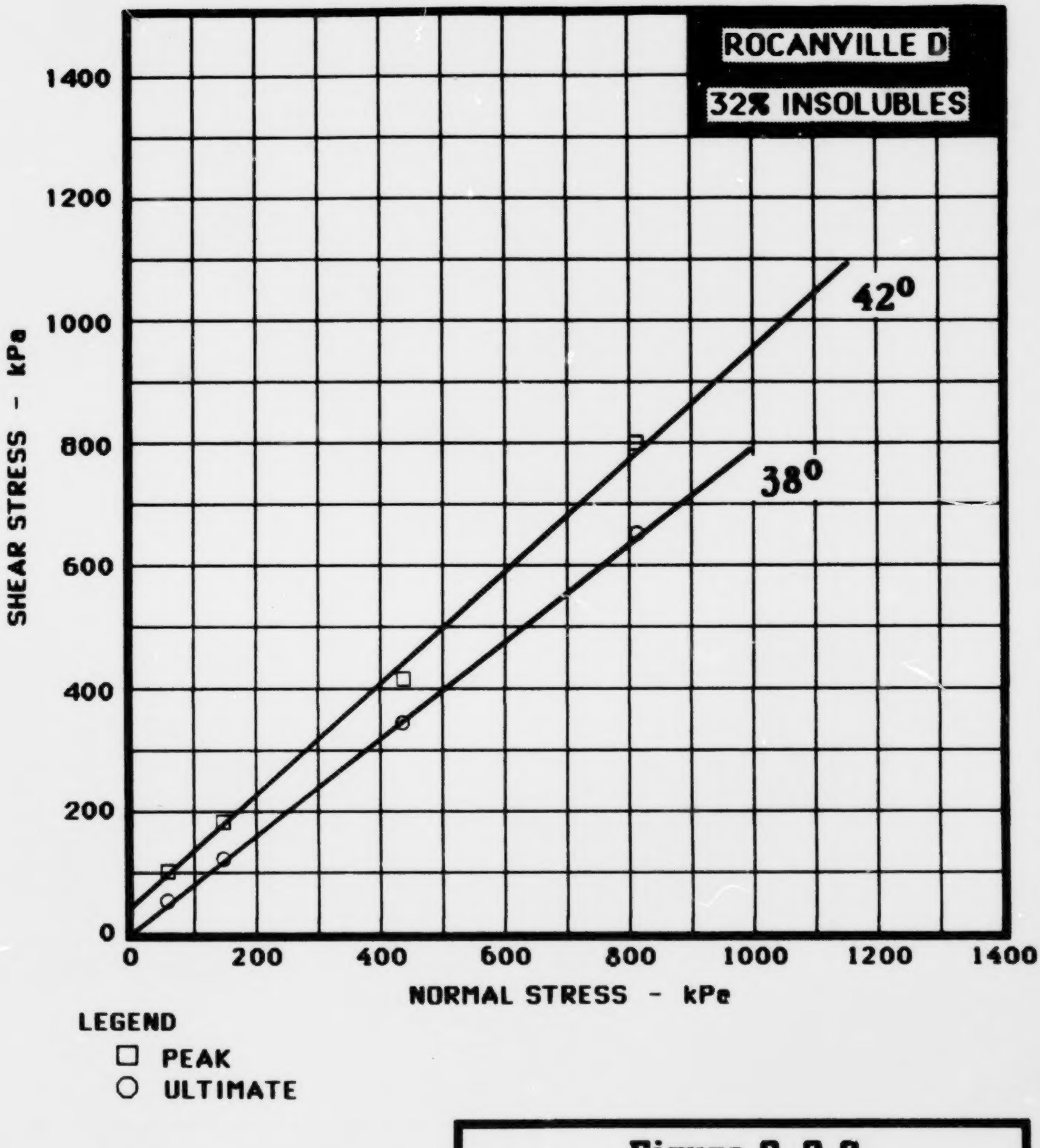


Figure A-2.9

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
ROCANVILLE D - 32% INSOLUBLES

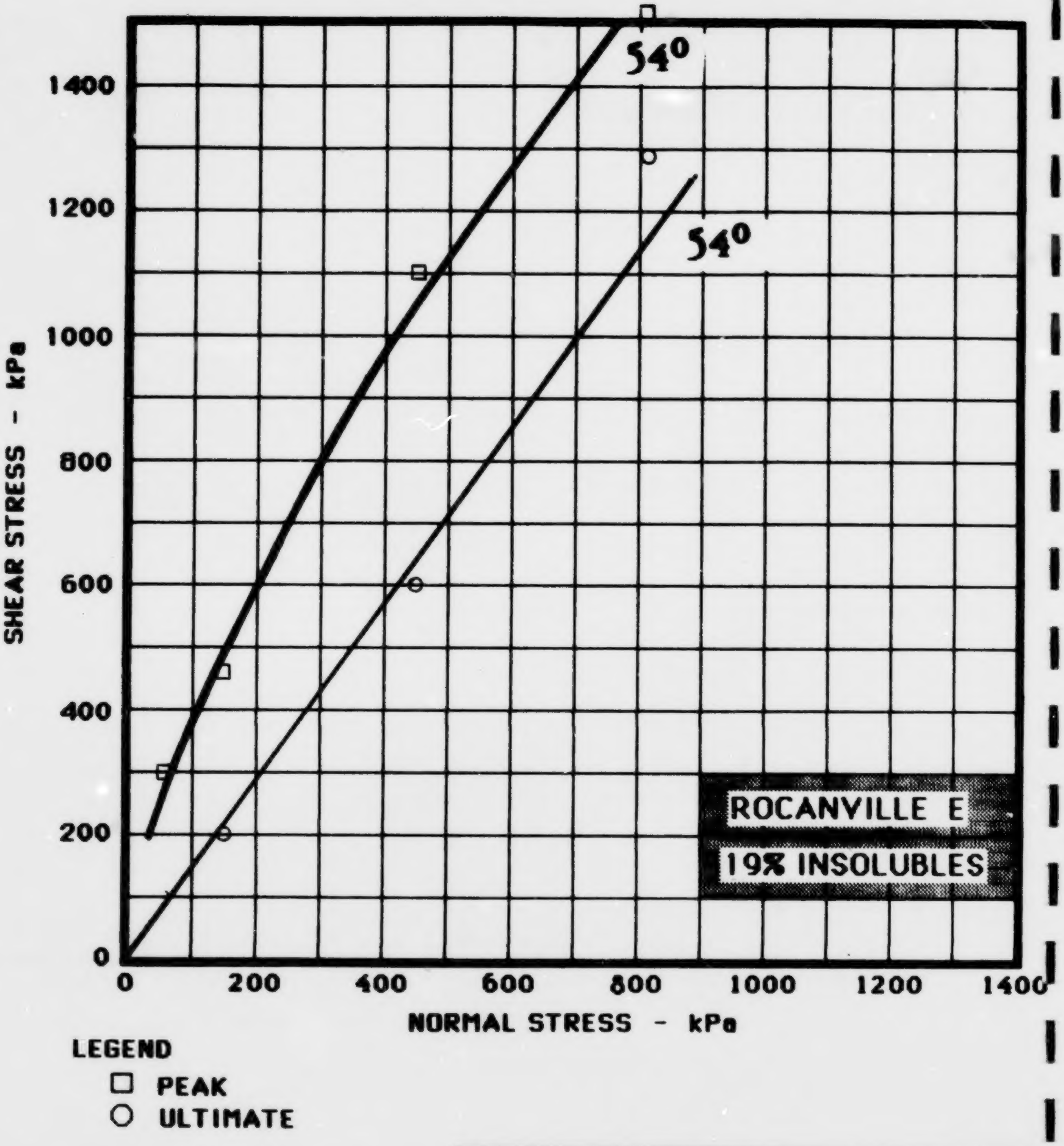


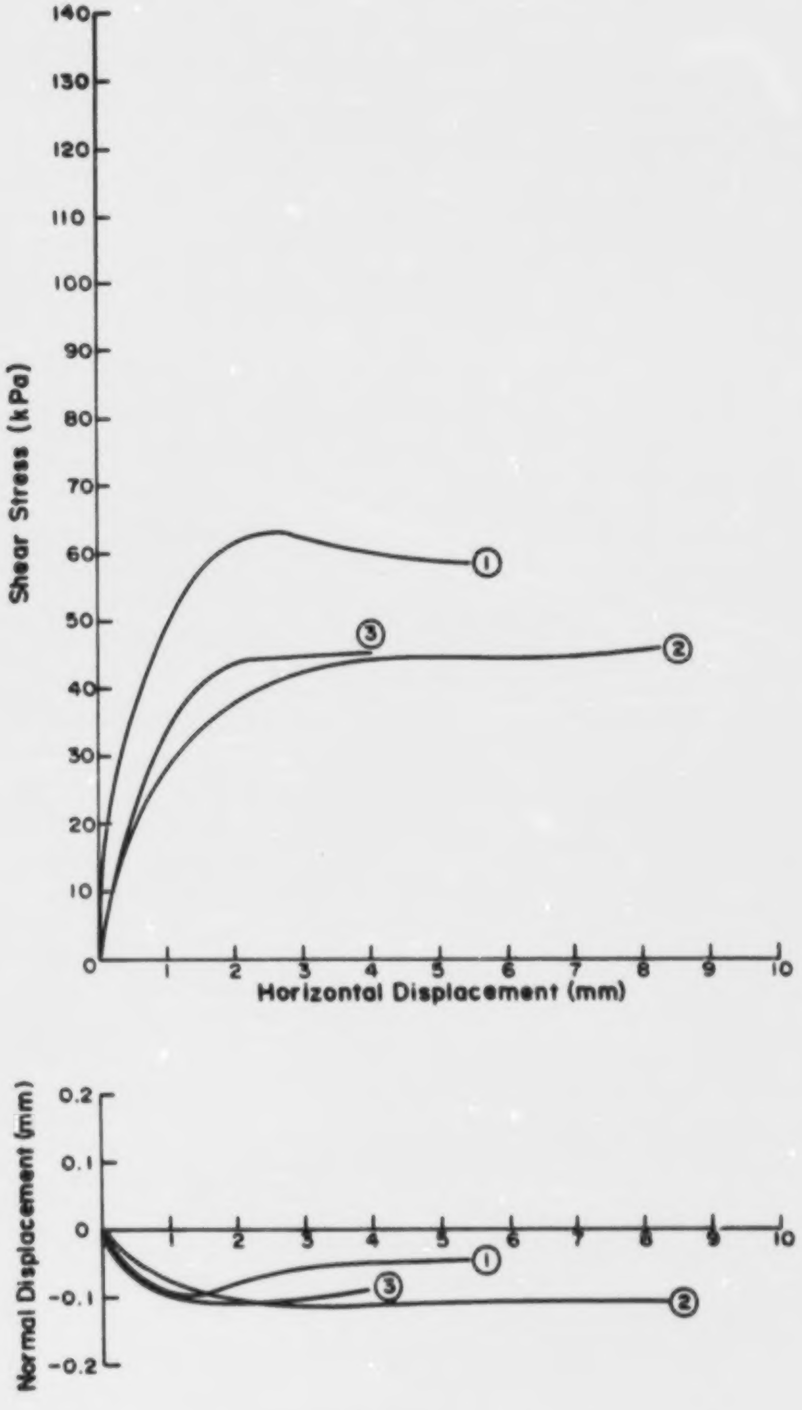
Figure A-2.10

MOHR-COULOMB FAILURE ENVELOPE
DIRECT SHEAR TEST
ROCANVILLE E - 19% INSOLUBLES

STRESS-DISPLACEMENT PLOTS

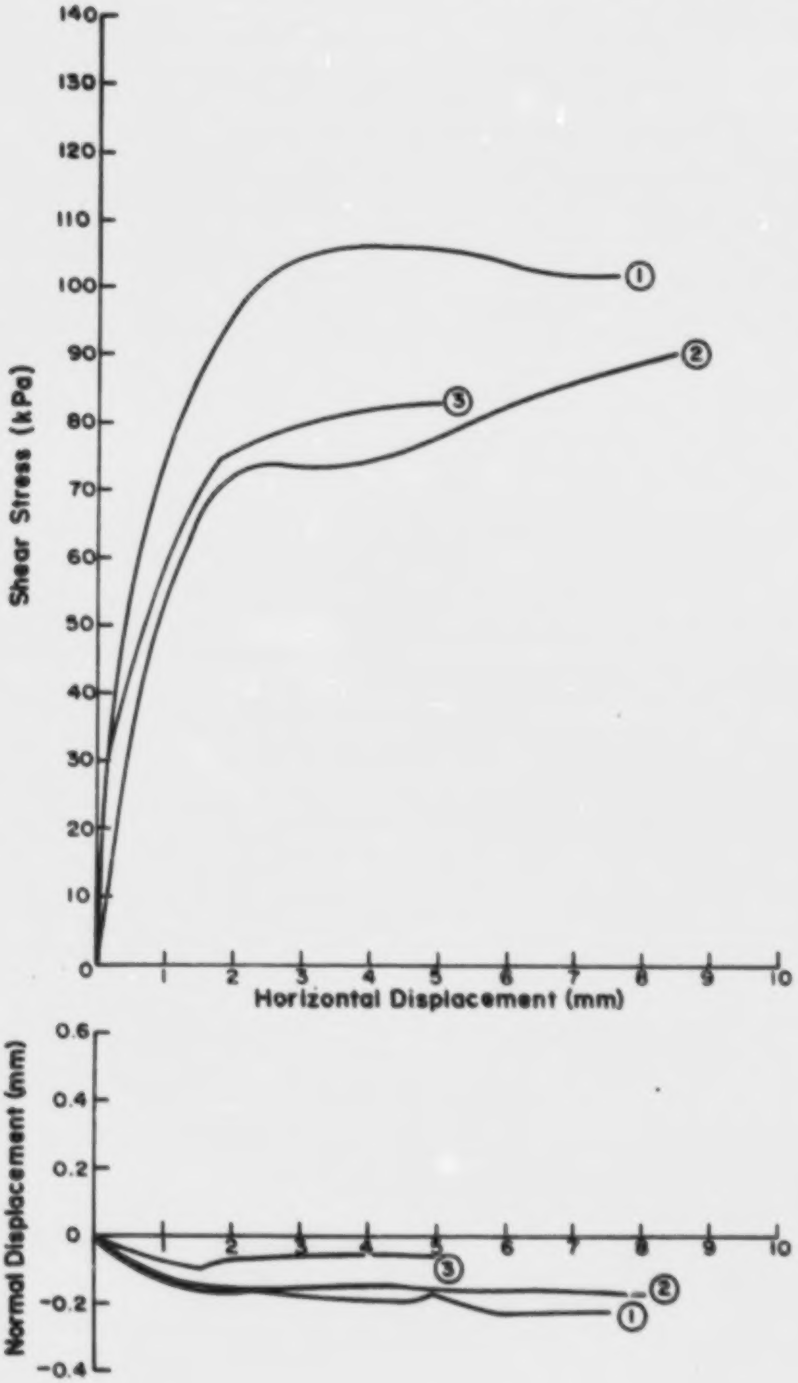
Direct Shear Tests

Effective Normal Stress = 70 kPa



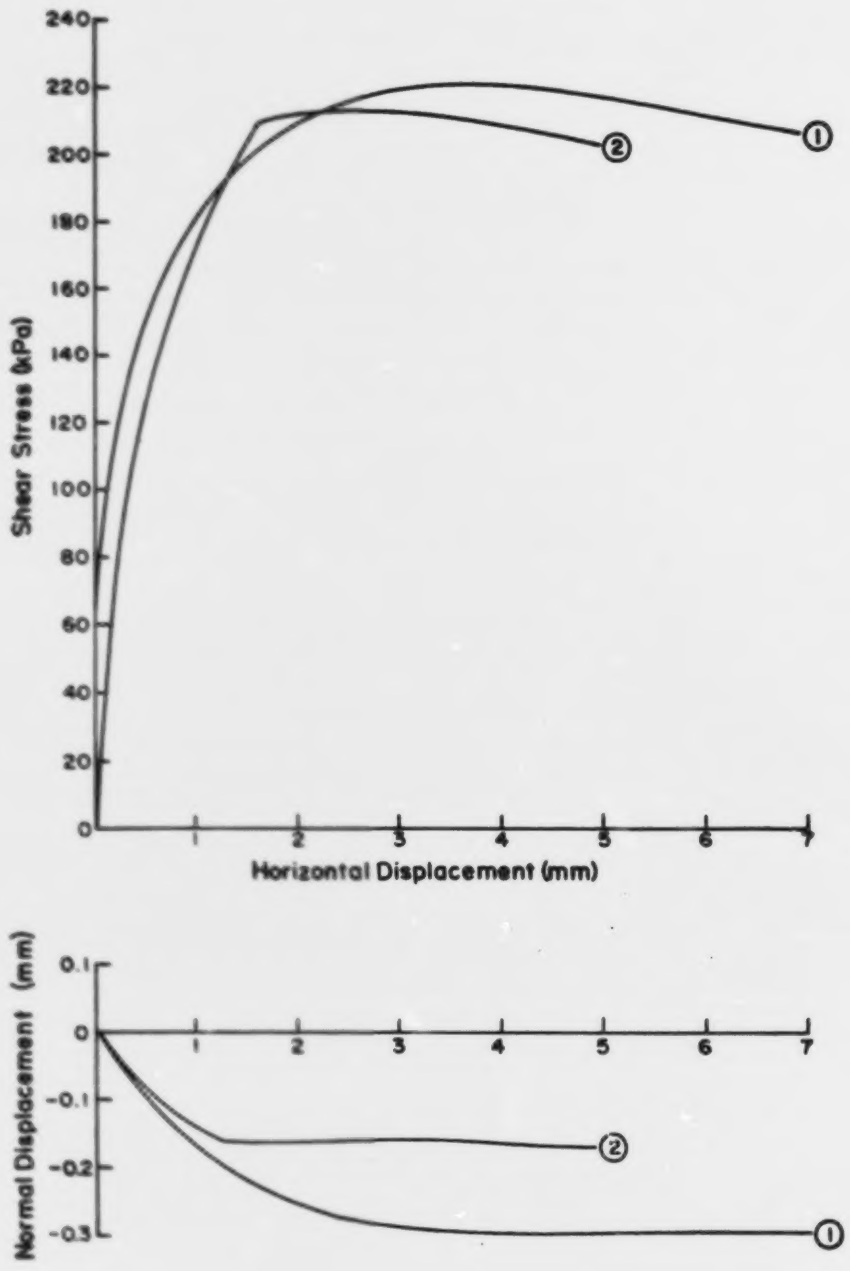
SECTION:		LOCATION: Cory	TITLE: Direct Shear Test Cory A Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY:	SEPT. 1984			DWG. No 2 1
CHECKED BY:				SH. of
APPROVED BY:				REV.

Effective Normal Stress = 150 kPa



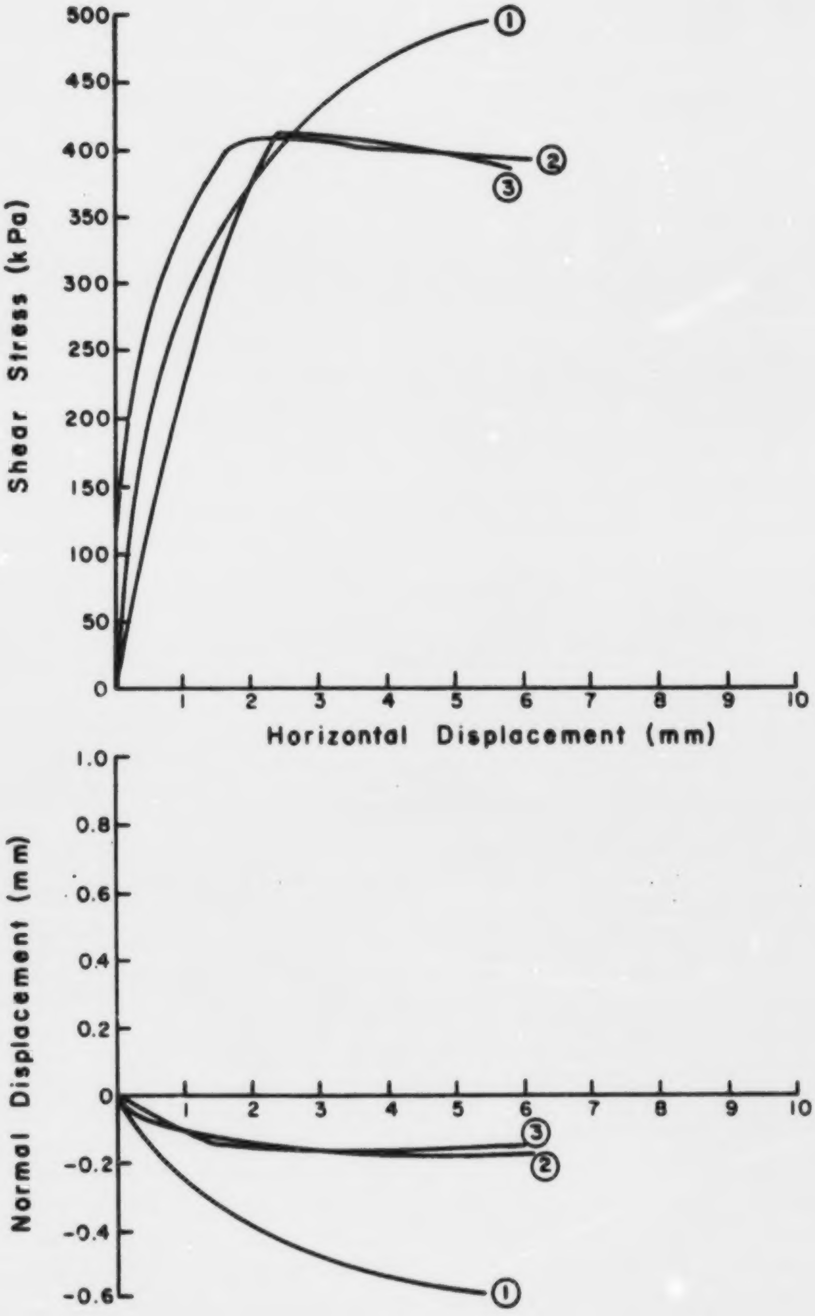
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory A Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY:	SEPT. 1984			DWG. No 2 2
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 450 kPa



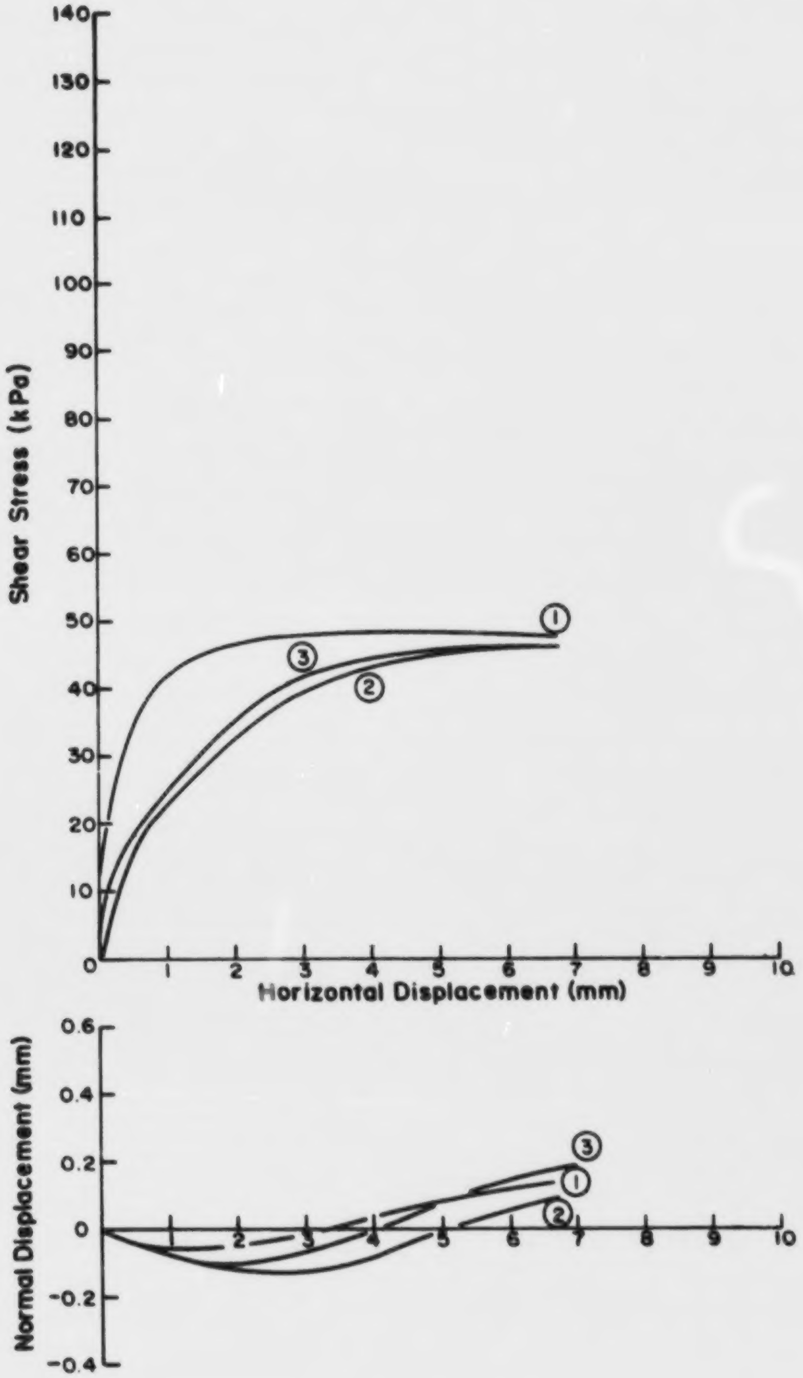
SECTION:		LOCATION: Cory	TITLE: Direct Shear Test Cory A Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: P.R.	SEPT. 1984			DWG. No 2 3
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 800 kPa



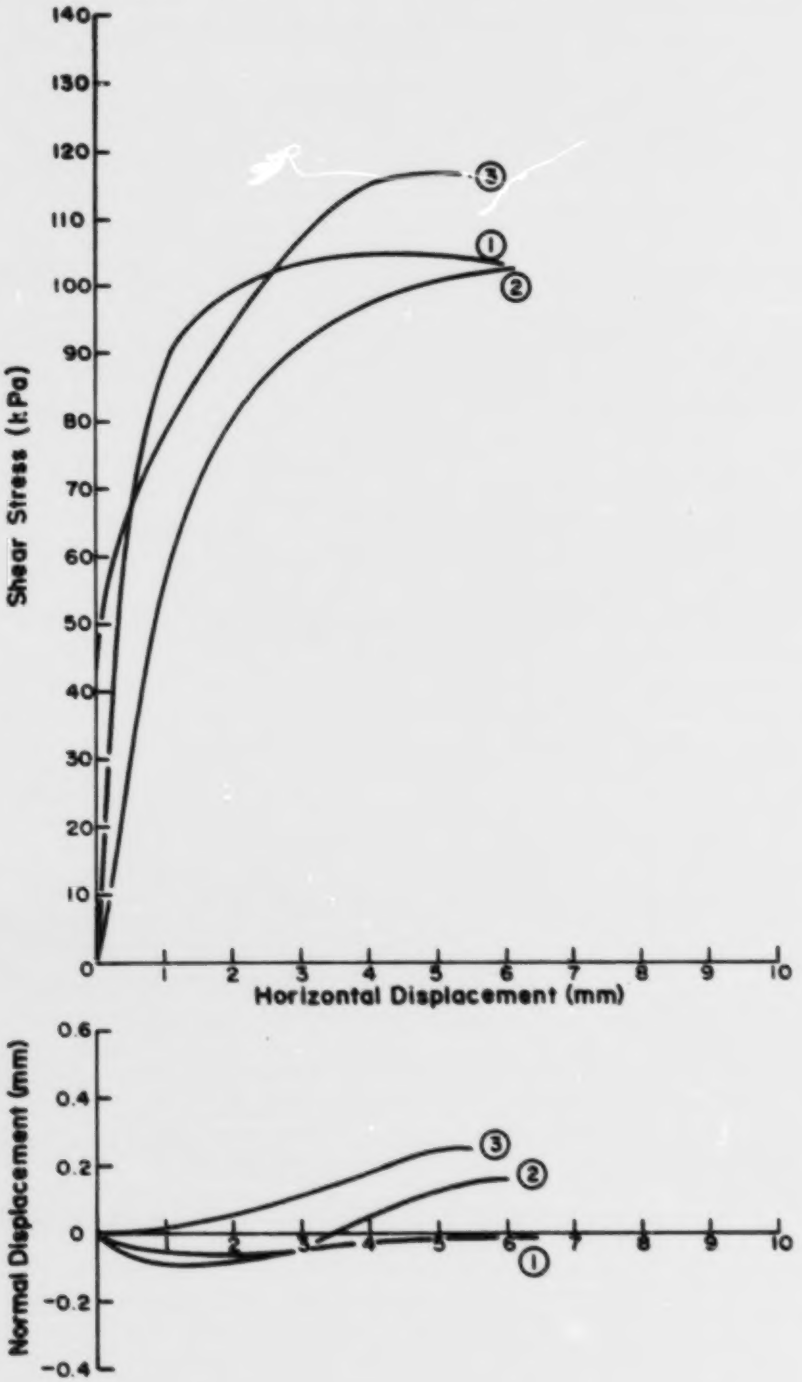
SECTION:		**LOCATION:** Cory	**TITLE:** Direct Shear Test Cory A Insolubles	**M.C.C. No.**
SCALE:	**DATE**			**ACC'T No.**
DESIGNED BY:		Potash Corporation of Saskatchewan		**PROJECT No**
DRAWN BY: P.R.	SEPT, 1984			**DWG. No** 2 4
CHECKED BY:				**SH.** of **REV.**
APPROVED BY:				

Effective Normal Stress = 65 kPa



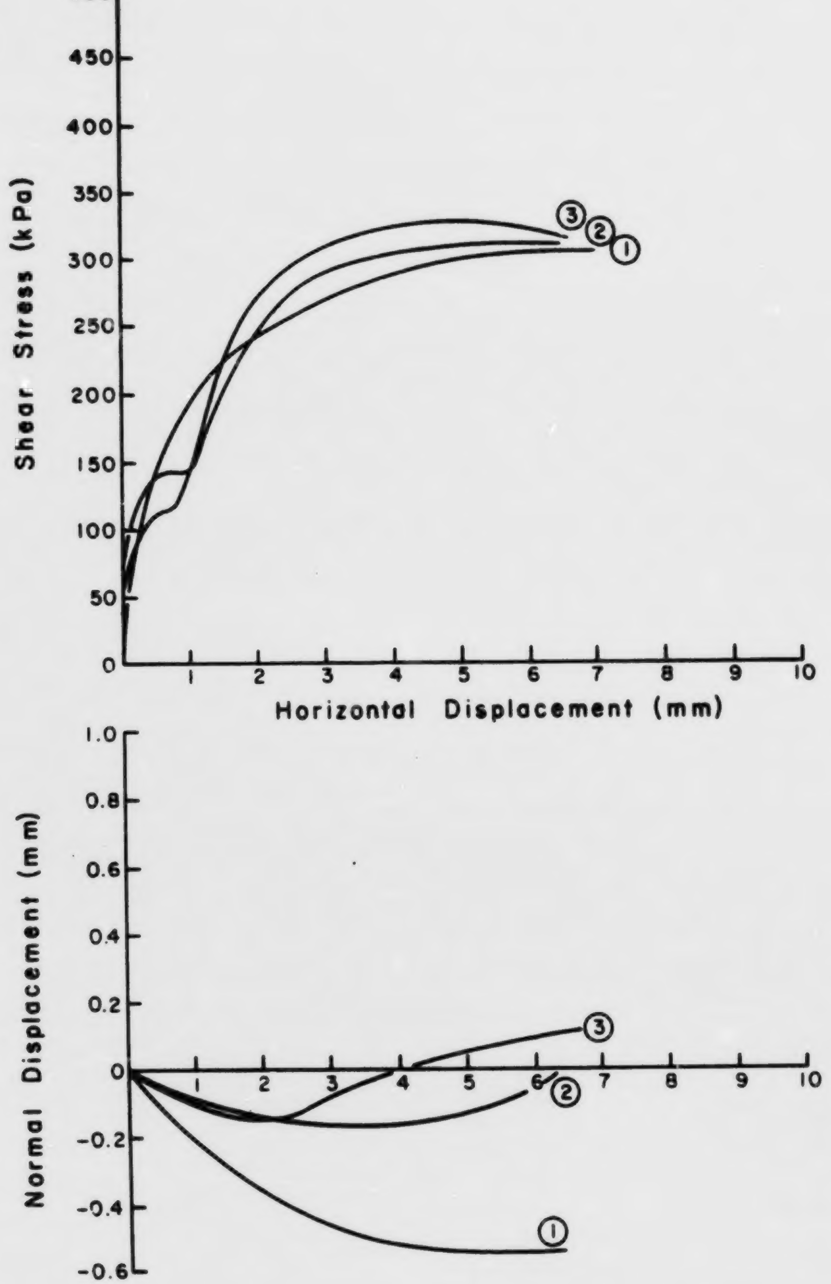
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory B-Slimes 33 % Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: LS	SEPT. 1984			DWG. No 2 5
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 143 kPa



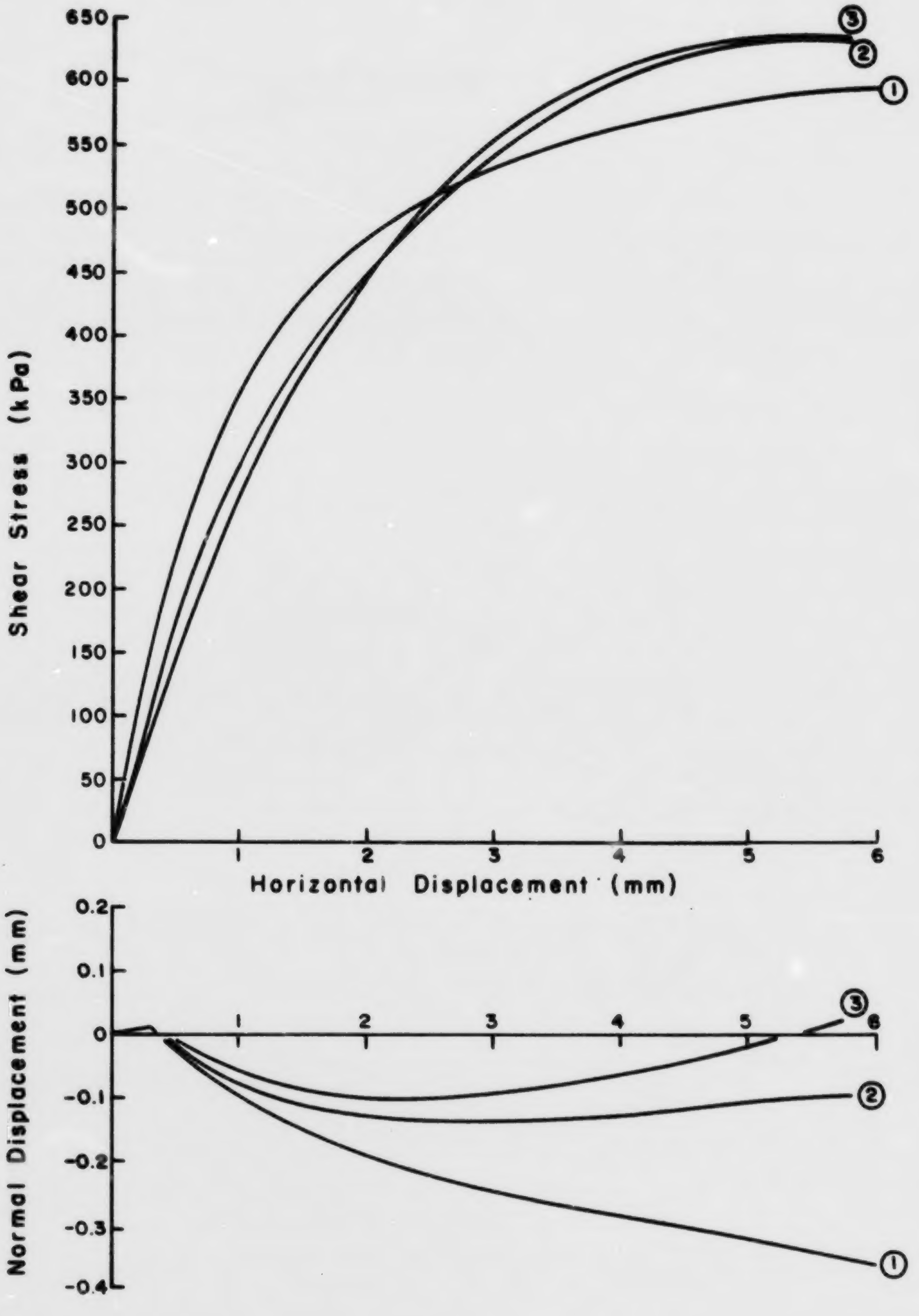
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:			Cory B – Slimes	PROJECT No
DRAWN BY: LG	SEPT. 1984	Potash Corporation of Saskatchewan	33 % Insolubles	DWG. No 2 6
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 438 kPa

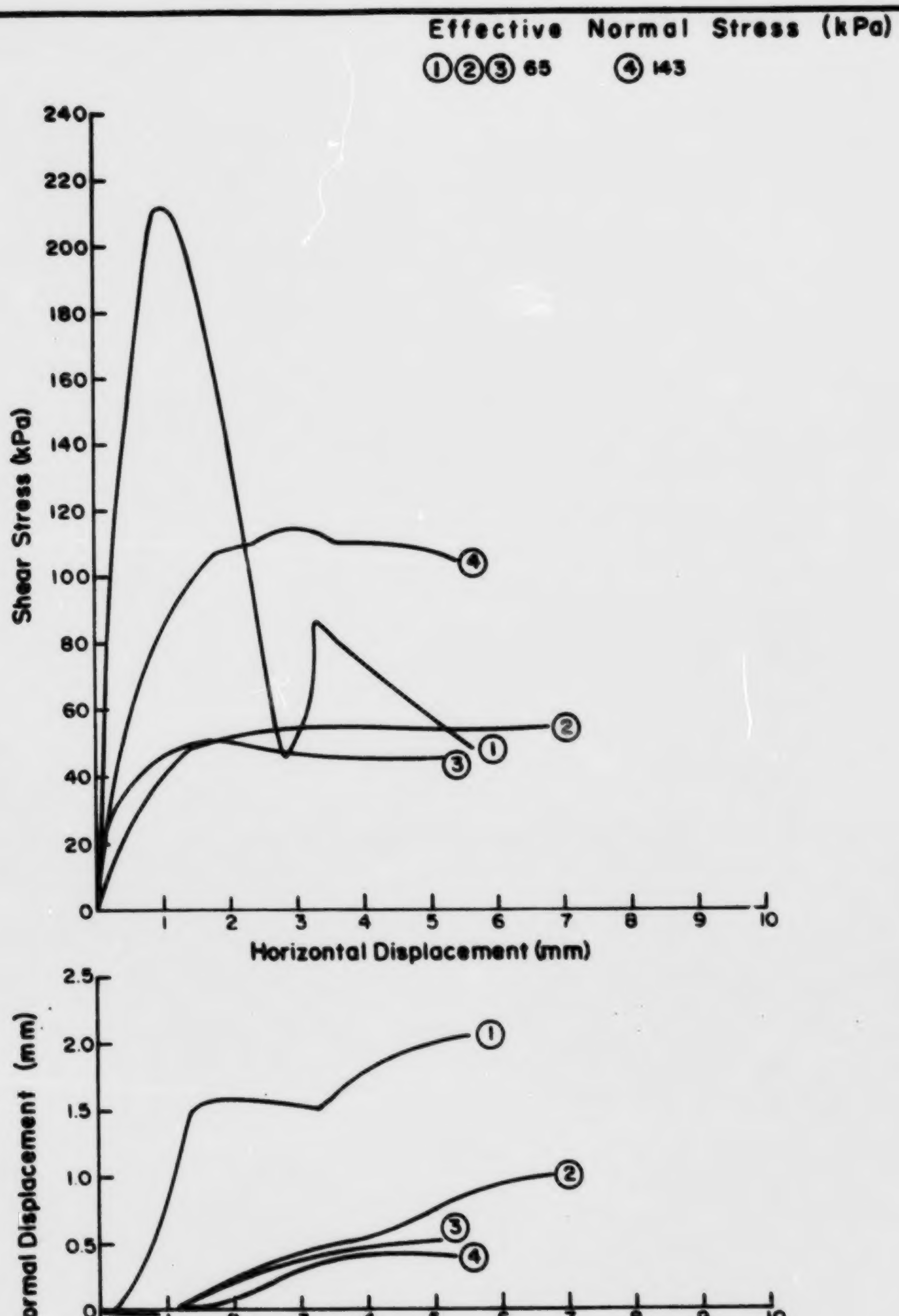


SECTION:		LOCATION: Cory	TITLE: Direct Shear Test Cory B – Slimes 33 % Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY:	SEPT, 1984			DWG. No 2 7
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 810 kPa

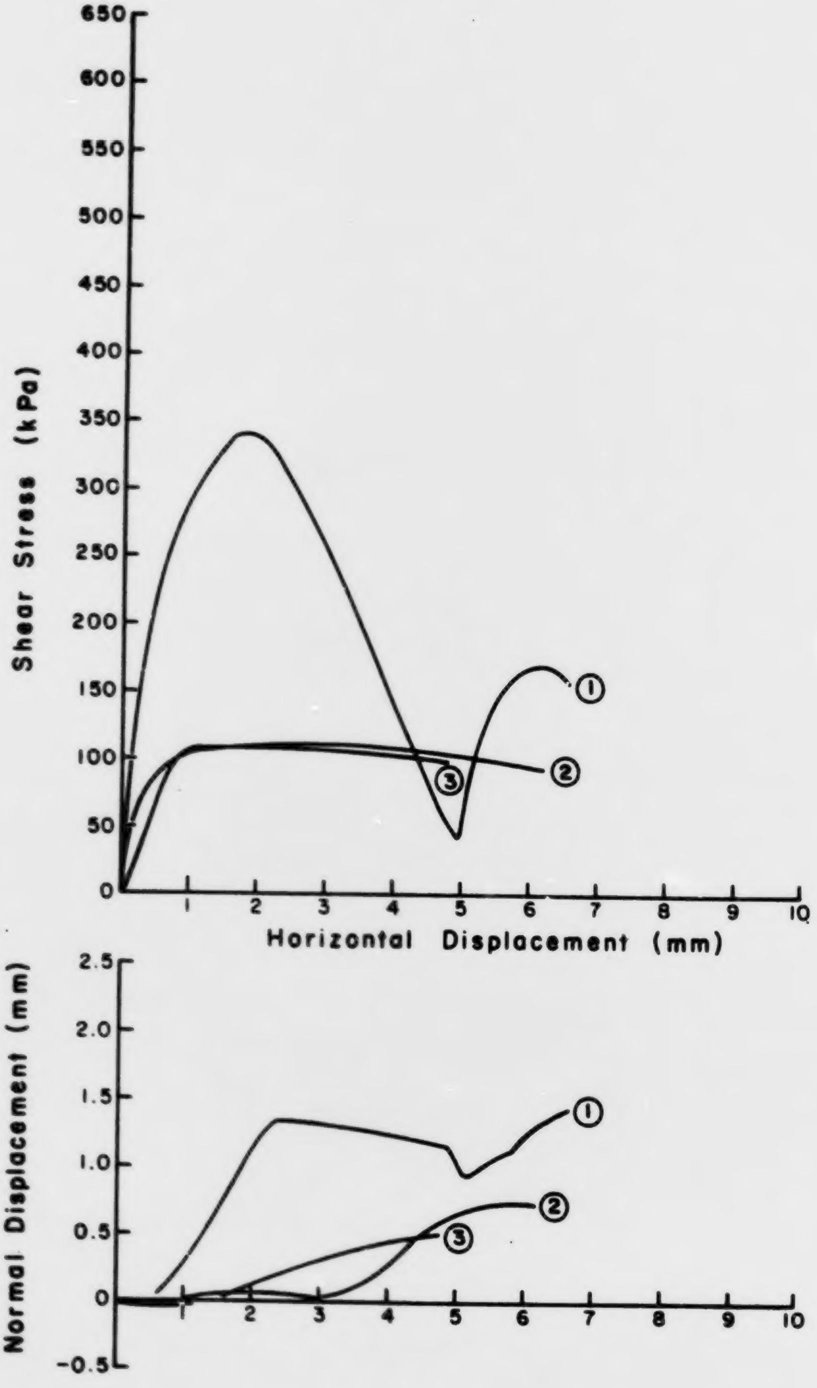


SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:			Cory B – Slimes	PROJECT No
DRAWN BY: cs	SEPT, 1984	Potash Corporation of Saskatchewan	33 % Insolubles	DWG. No. 2 8
CHECKED BY:				
APPROVED BY:				SH. of REV.



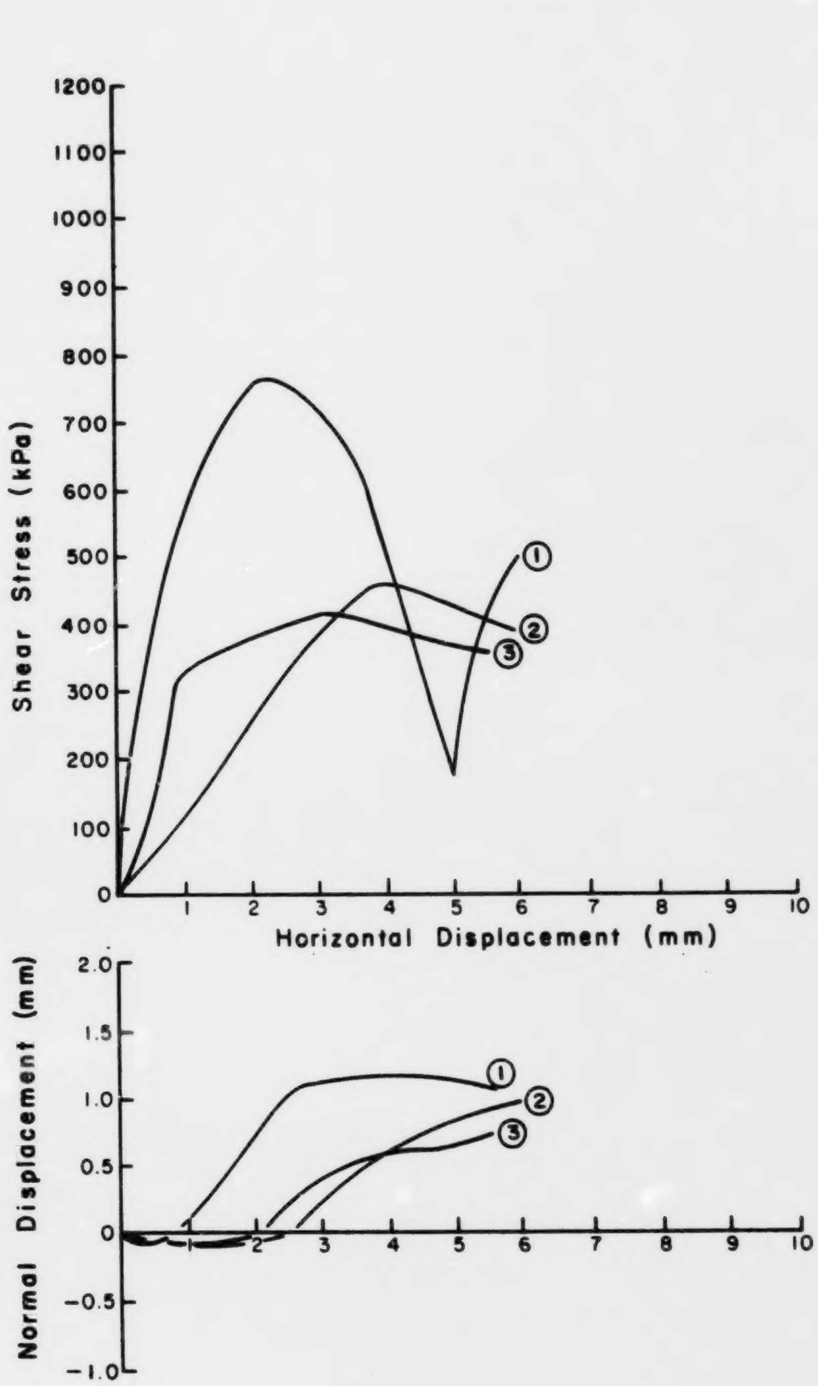
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:				PROJECT No
DRAWN BY: P.R.	SEPT. 1984	Potash Corporation of Saskatchewan	Cory C	DWG. No 2 9
CHECKED BY:			Salt Tails	
APPROVED BY:				SH. of REV.

Effective Normal Stress = 143 kPa



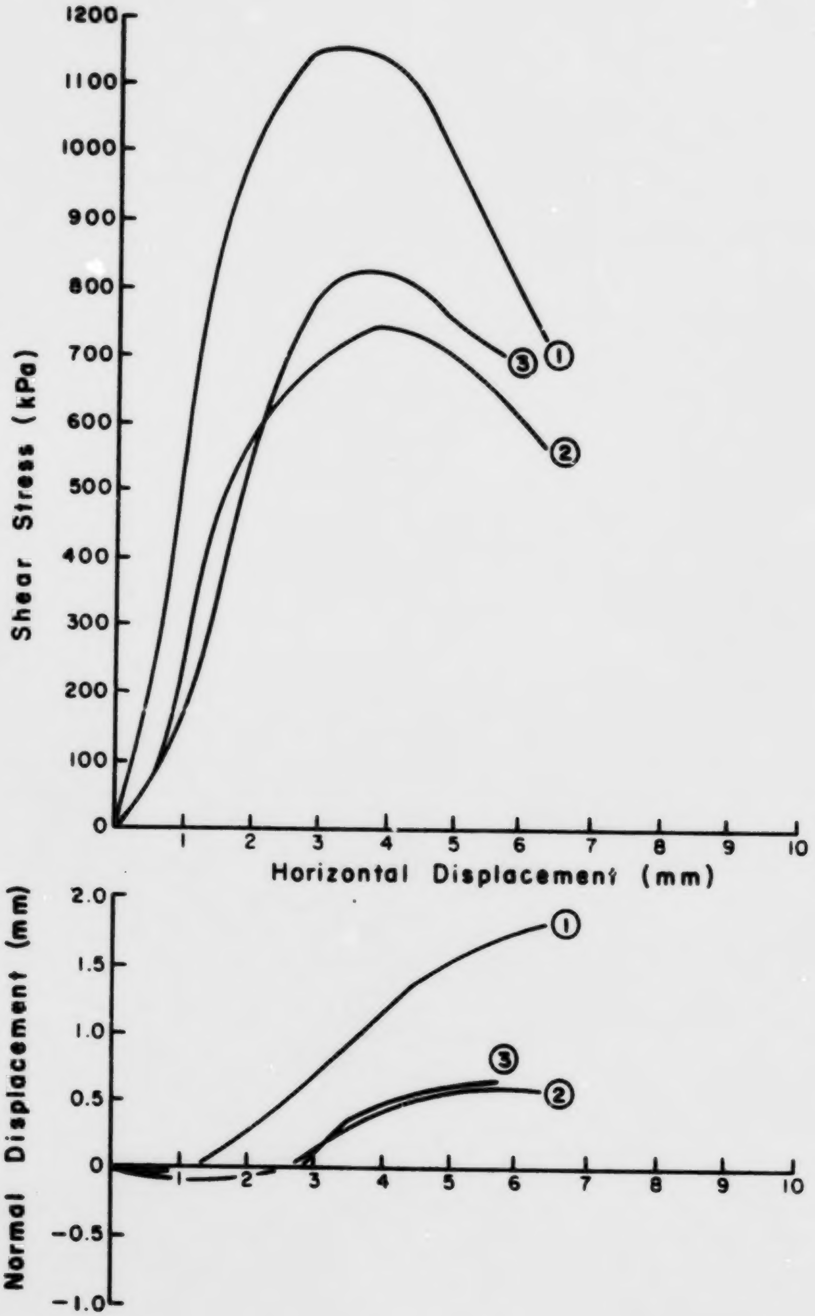
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:				PROJECT No
DRAWN BY: P.A.	SEPT, 1984	Potash Corporation of Saskatchewan	Cory C	DWG. No. 2 10
CHECKED BY:				
APPROVED BY:			Salt Tails	SH. of	REV.

Effective Normal Stress = 438 kPa



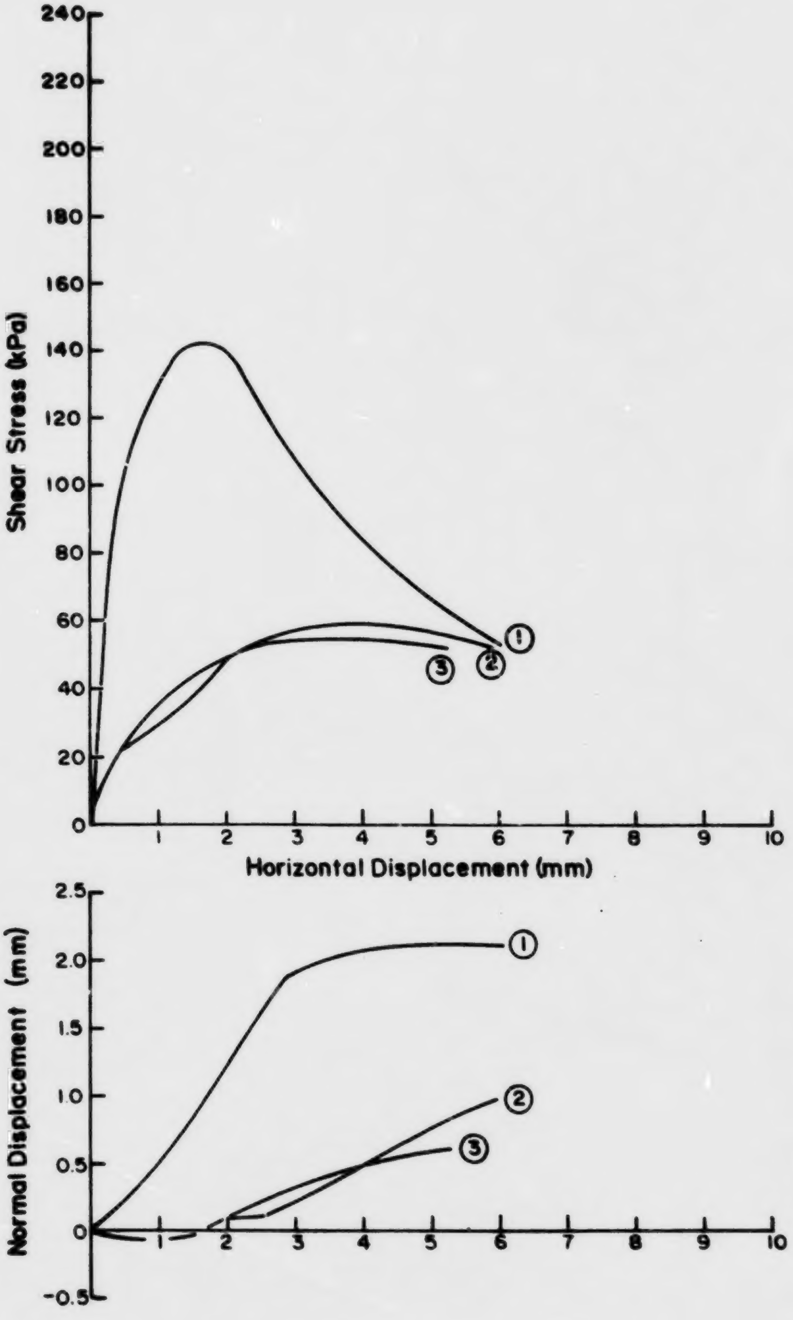
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:			Direct Shear Test	PROJECT No
DRAWN BY: P.R.	SEPT, 1984	Potash Corporation of Saskatchewan	Cory C	DWG. No 2 11
CHECKED BY:				
APPROVED BY:			Salt Tails	SH. of REV.

Effective Normal Stress = 810 kPa



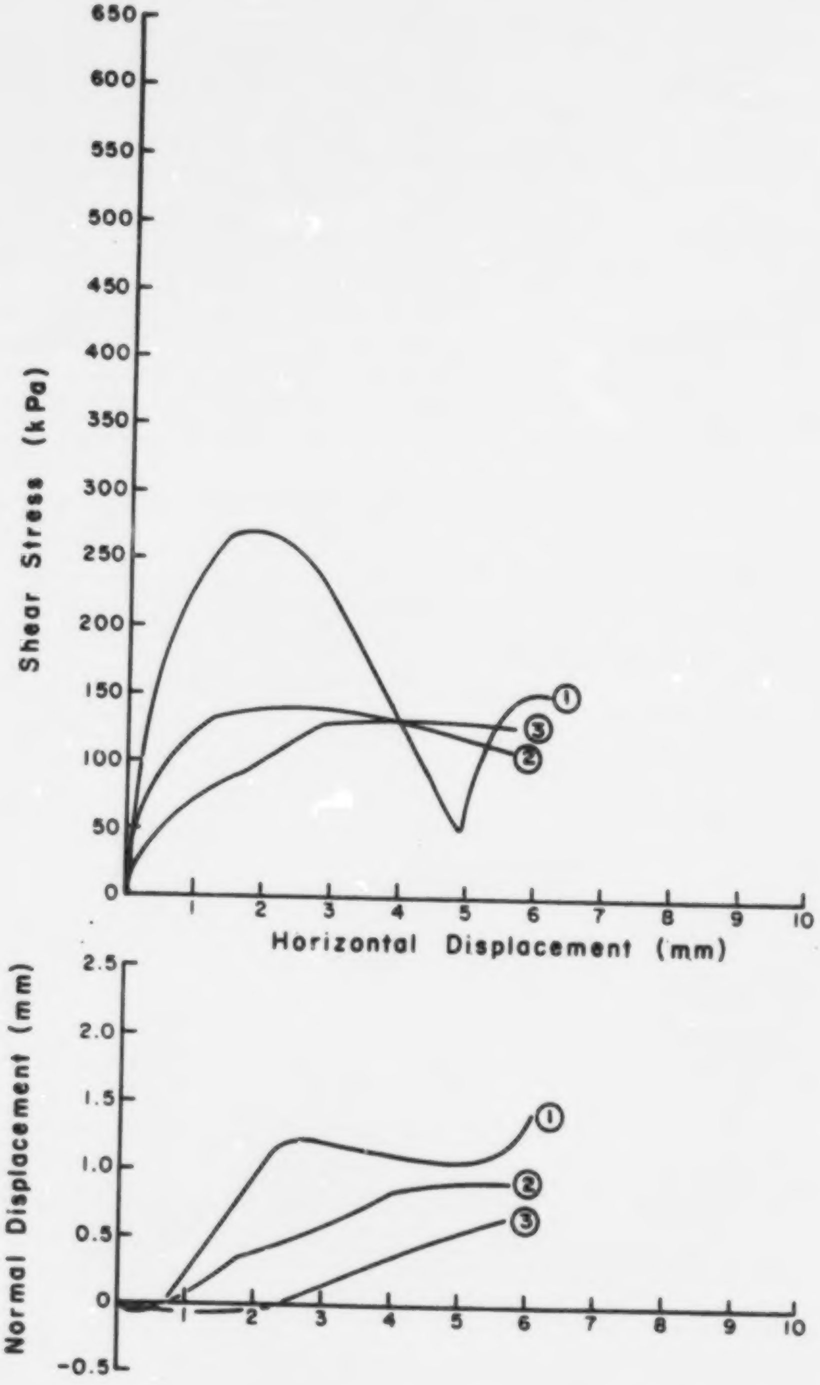
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory C Salt Tails	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: P.R.	SEPT, 1984			DWG. No 2 12
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Normal Stress = 65 kPa



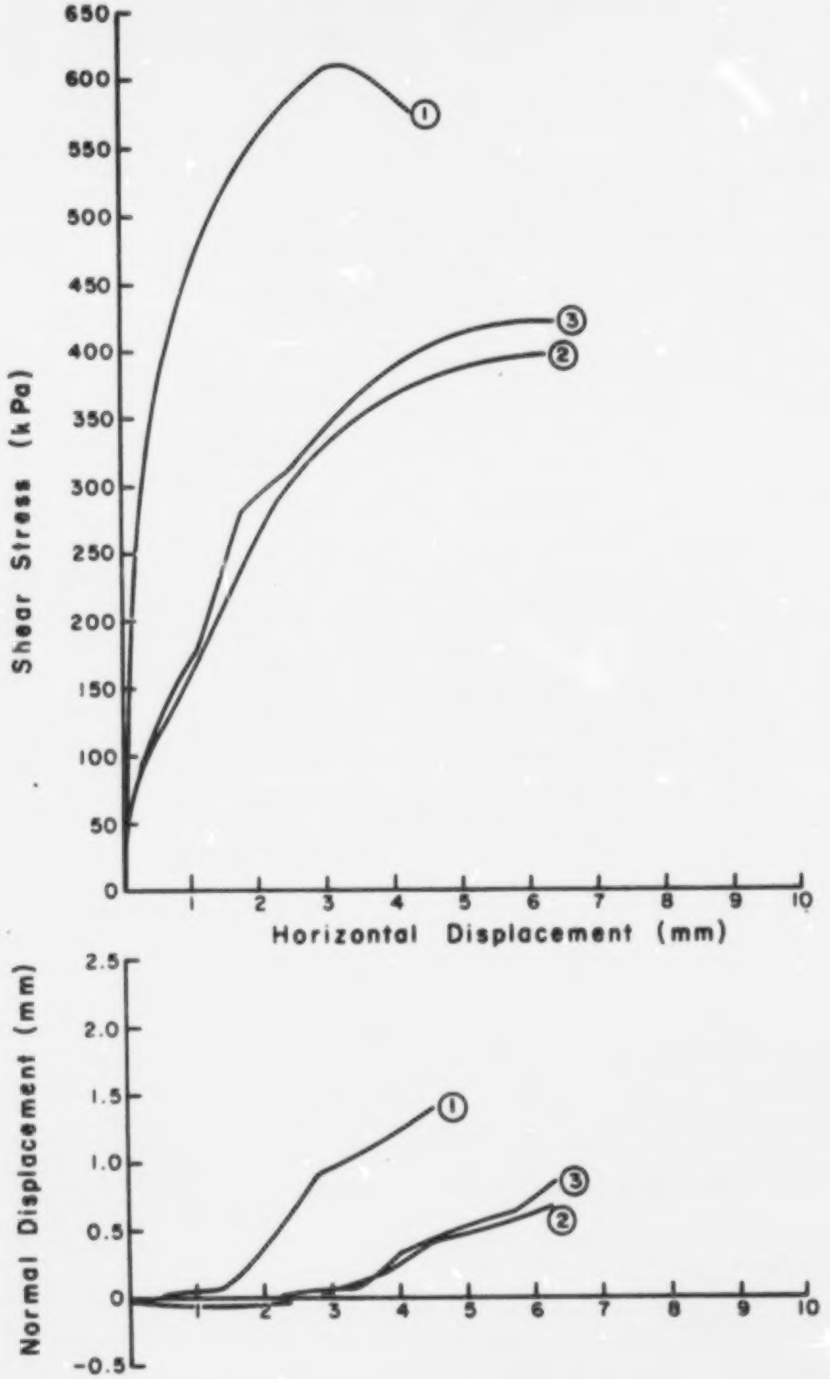
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory D-Salt 10% Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: P.R.	SEPT. 1984			DWG. No 2 13
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 143 kPa



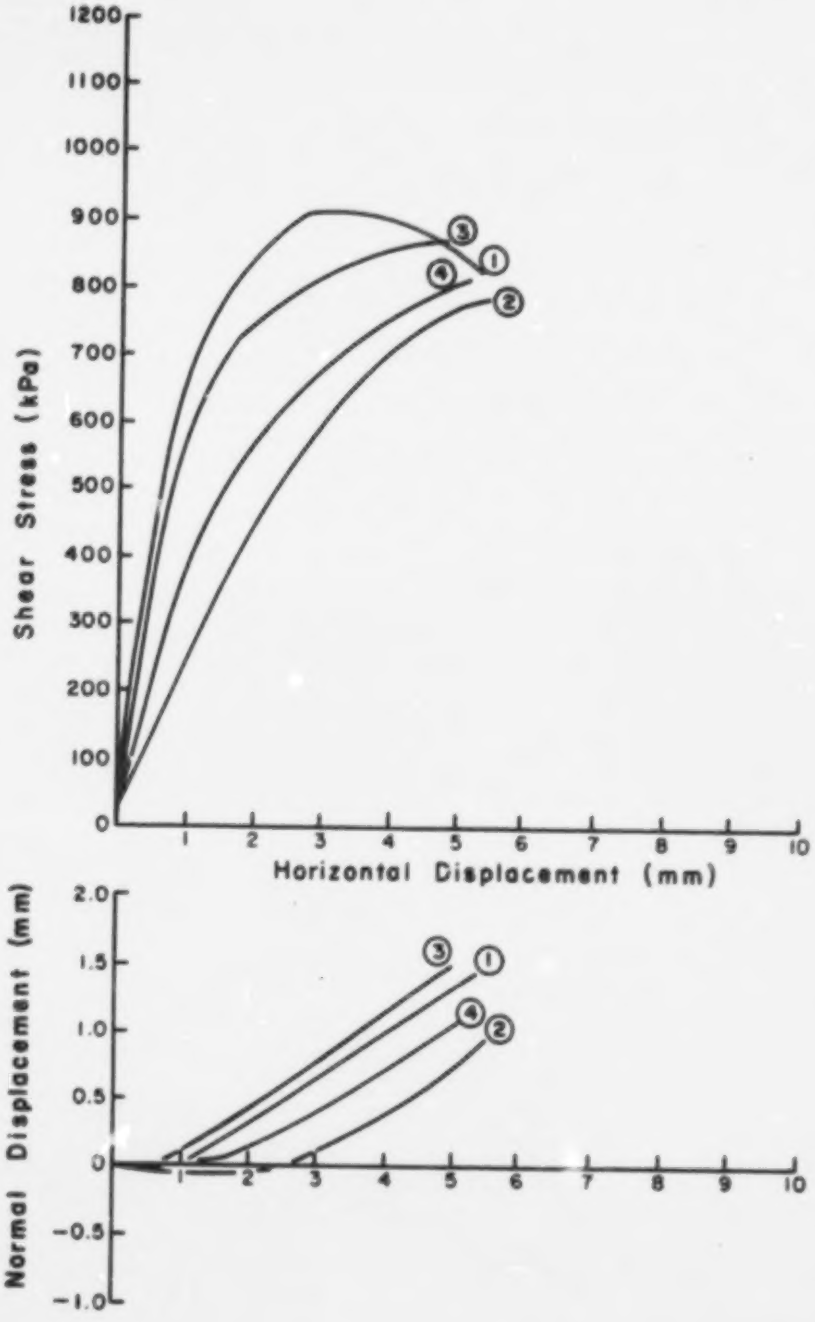
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory D-Salt 10% Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: P.R.	SEPT, 1984			DWG. No 2 14
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 438 kPa



SECTION:		LOCATION: Cory	TITLE: Direct Shear Test Cory D-Salt 10% Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:				PROJECT No
DRAWN BY: A.A.	SEPT, 1984	Potash Corporation of Saskatchewan		DWG. No 2 15
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Normal Stress = 810 kPa



SECTION:
SCALE:
DATE
DESIGNED BY:
DRAWN BY: P.R.
SEPT, 1984
CHECKED BY:
APPROVED BY:

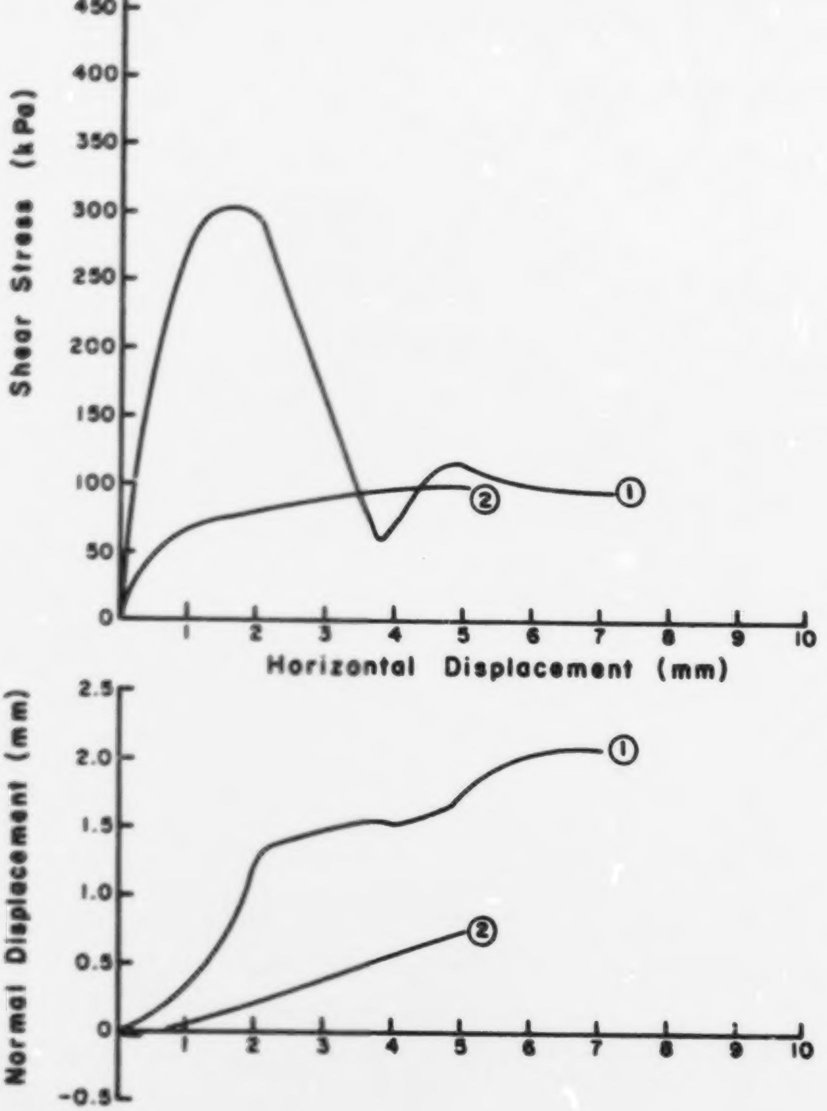
LOCATION:
Cory

Potash Corporation of Saskatchewan

TITLE:
Direct Shear Test
Cory D-Salt
10% Insolubles

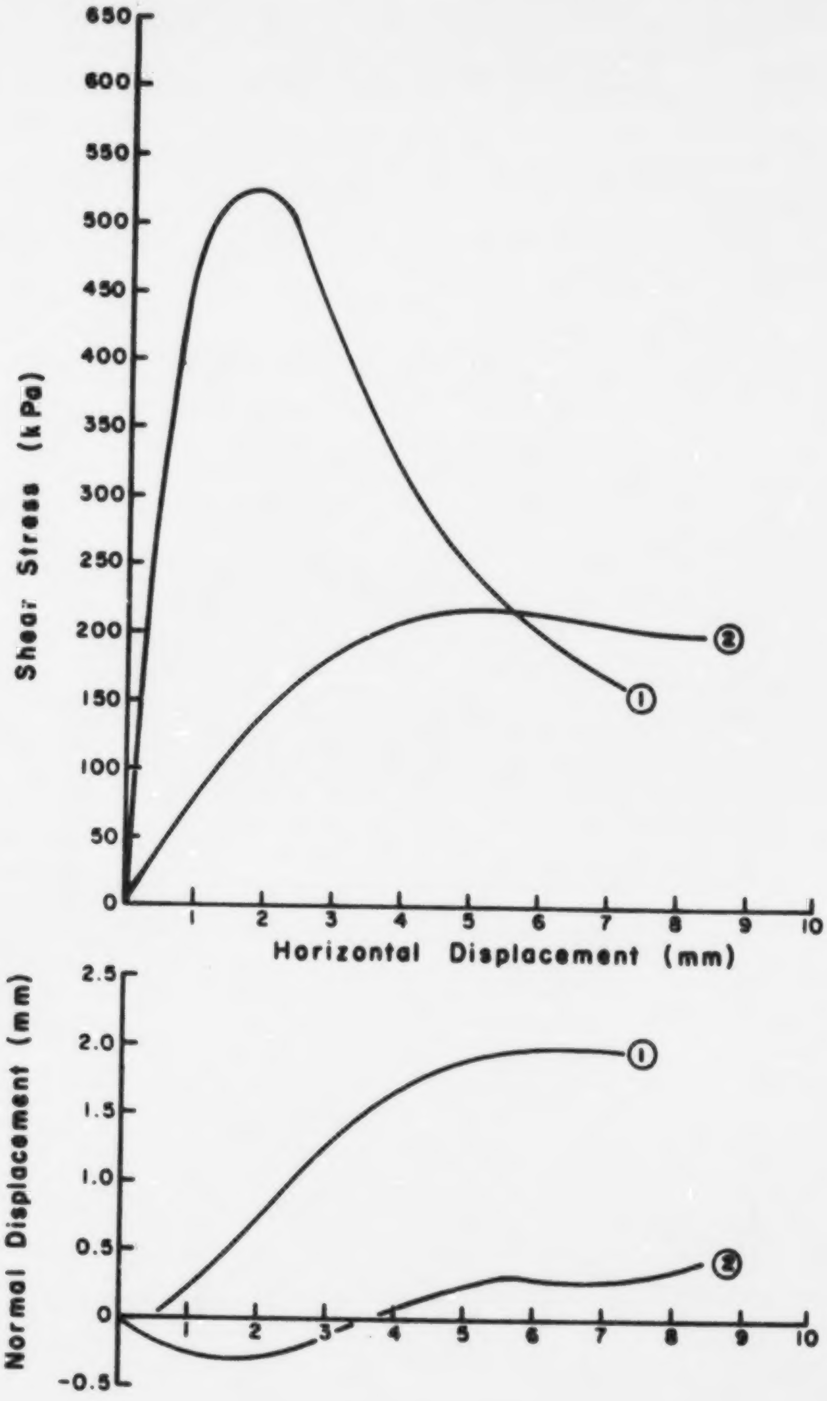
M.C.C. No.
ACC'T No.
PROJECT No
DWG. No 2 16
SH. of
REV.

Effective Normal Stress = 72 kPa



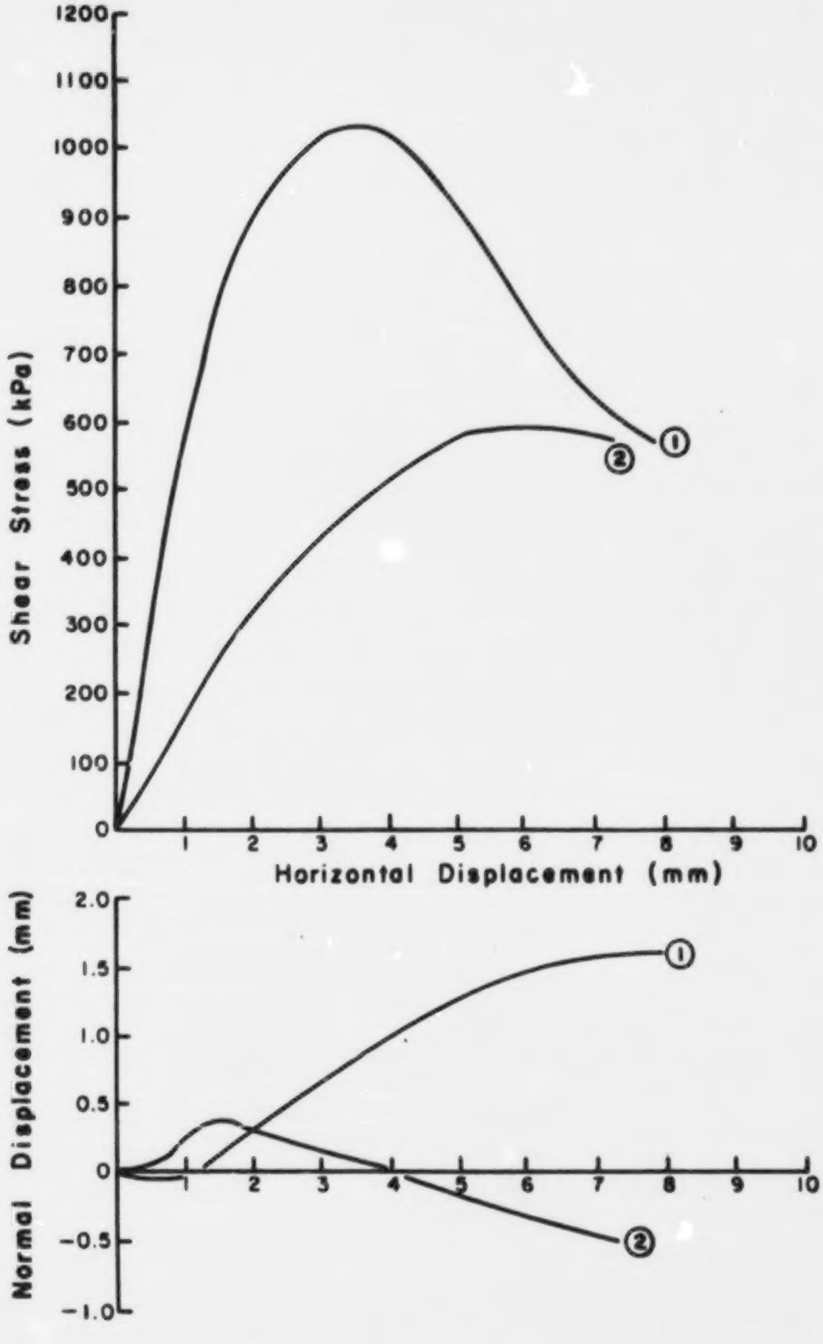
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Cory E-Salt 17% Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: P.A.	SEPT, 1984			DWG. No. 2 17
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 150 kPa



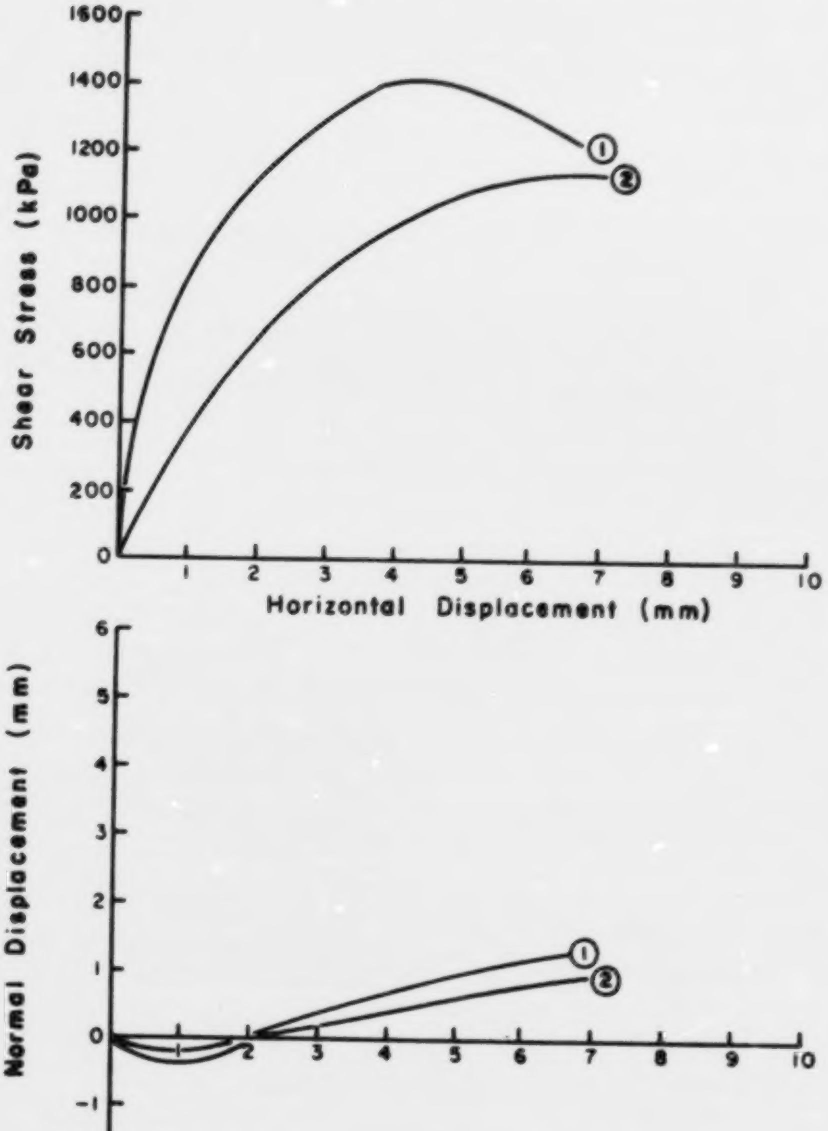
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:			Cory E-Salt	PROJECT No.
DRAWN BY: P.R.	SEPT, 1984	Potash Corporation of Saskatchewan	17% Insolubles	DWG. No. 2 18
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 450 kPa



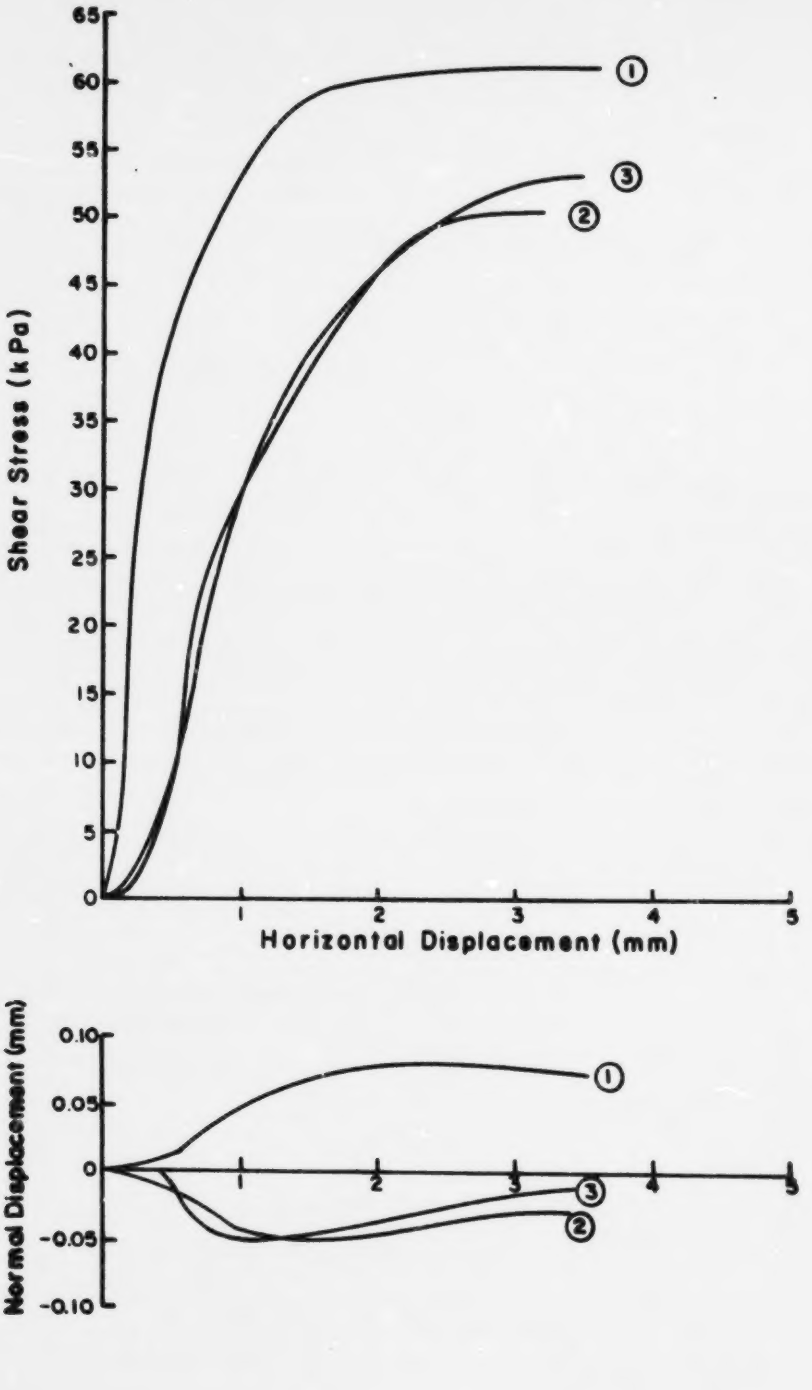
SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Cory		ACC'T No.
DESIGNED BY:			Direct Shear Test	PROJECT No.
DRAWN BY: P.R.	SEPT, 1984	Potash Corporation of Saskatchewan	Cory E-Salt	DWG. No. 2 19
CHECKED BY:			17% Insolubles	
APPROVED BY:				SH. of REV.

Effective Normal Stress = 784 kPa



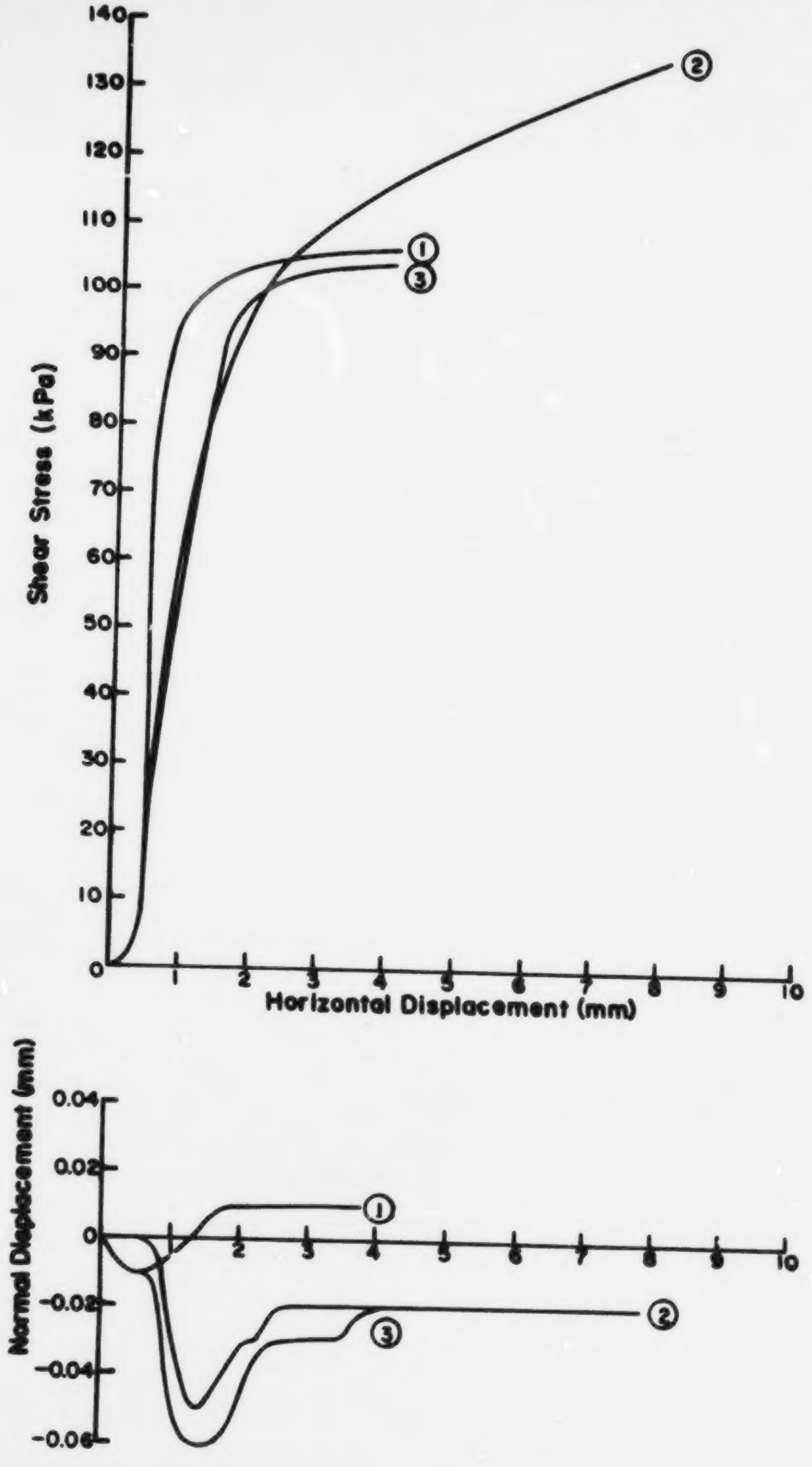
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:			Cory E-Salt	PROJECT No
DRAWN BY: F.B.	SEPT, 1984	Potash Corporation of Saskatchewan	17% Insolubles	DWG. No 2 20
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Normal Stress = 70 kPa



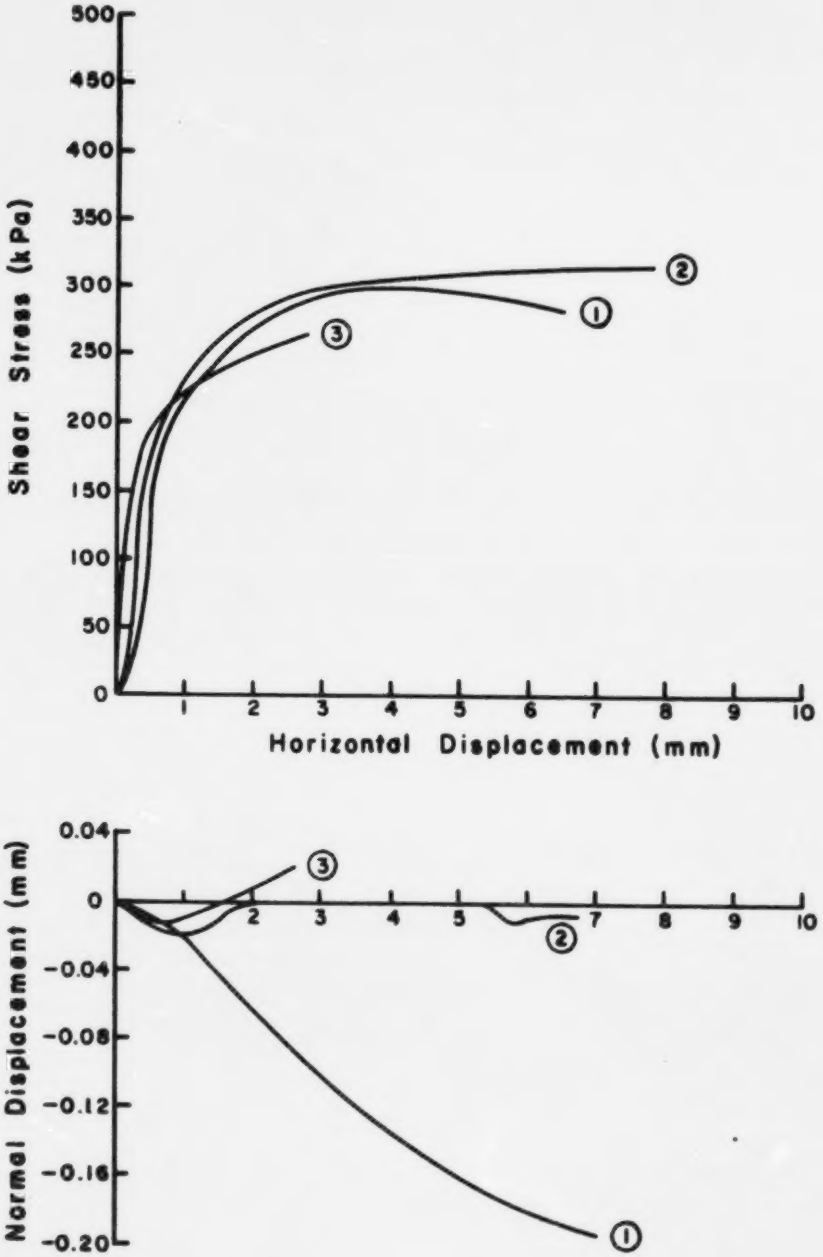
SECTION:		LOCATION: Rocanville	TITLE: Direct Shear Test Roc A Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY: LS	SEPT, 1984	Potash Corporation of Saskatchewan		DWG. No. 2 21
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 150 kPa



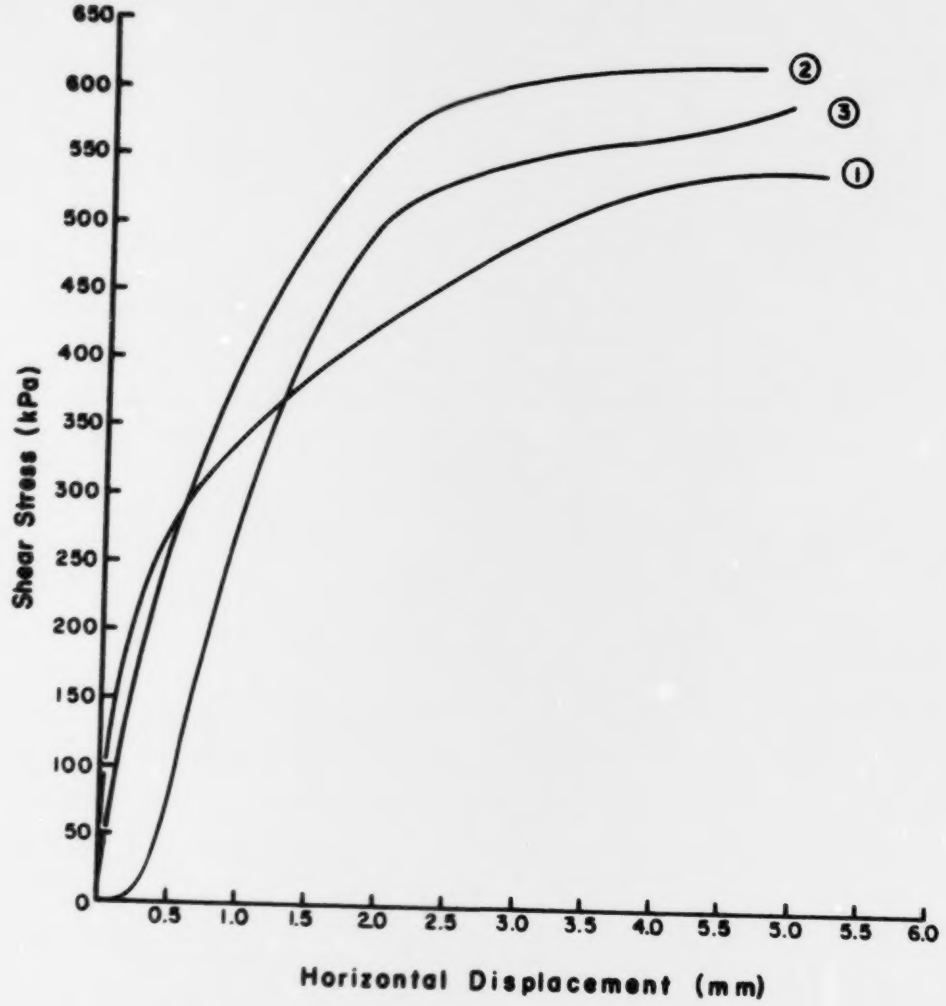
SECTION:		LOCATION: Rocanville	TITLE: Direct Shear Test Roc A Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: LS	SEPT. 1984			DWG. No. 2 22
CHECKED BY:				SH. of REV.
APPROVED BY:				

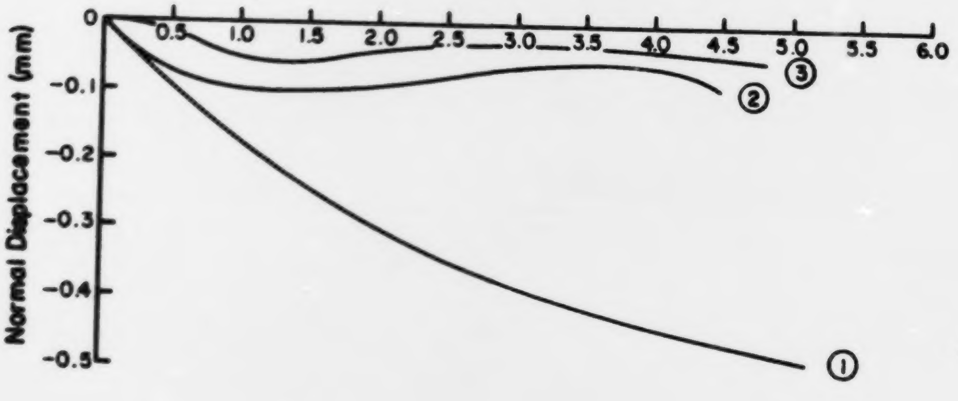
Effective Normal Stress = 450 kPa



SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY: LS	SEPT, 1984	Potash Corporation of Saskatchewan	Roc A	DWG. No. 2 23
CHECKED BY:			Insolubles	
APPROVED BY:				SH. of REV.

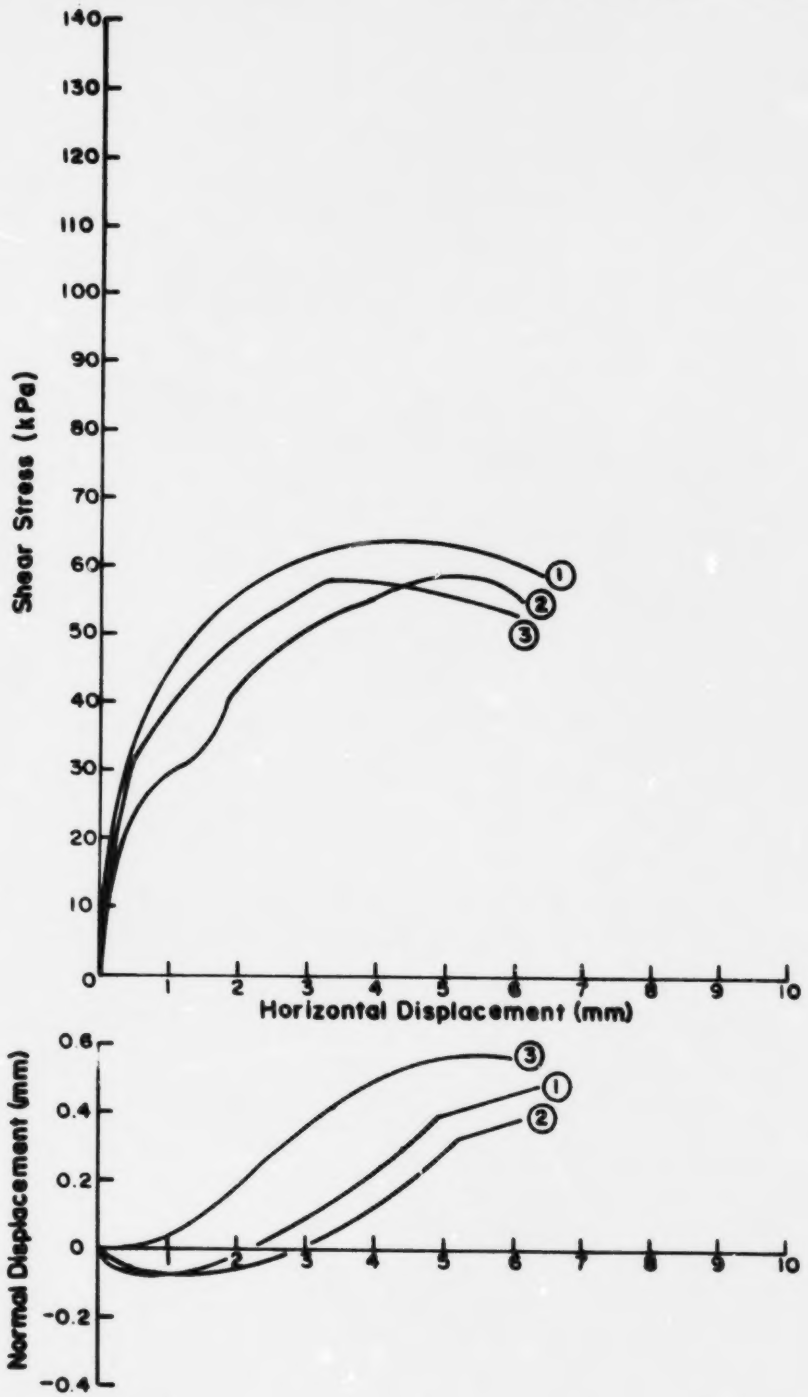
Effective Normal Stress = 800 kPa





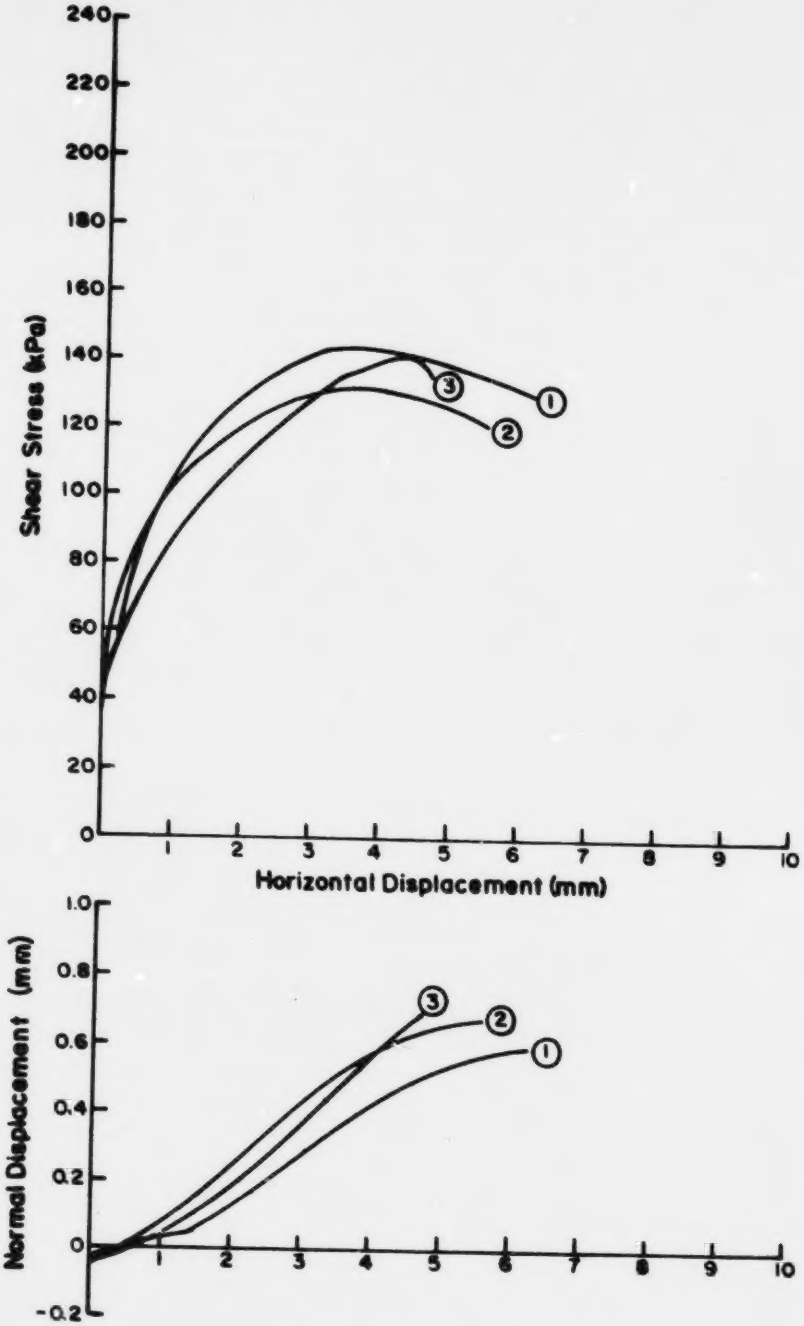
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc A	PROJECT No.
DRAWN BY: LS	SEPT, 1984		Insolubles	DWG. No. 2 24
CHECKED BY:				SH. of
APPROVED BY:				REV.

Effective Normal Stress = 65 kPa



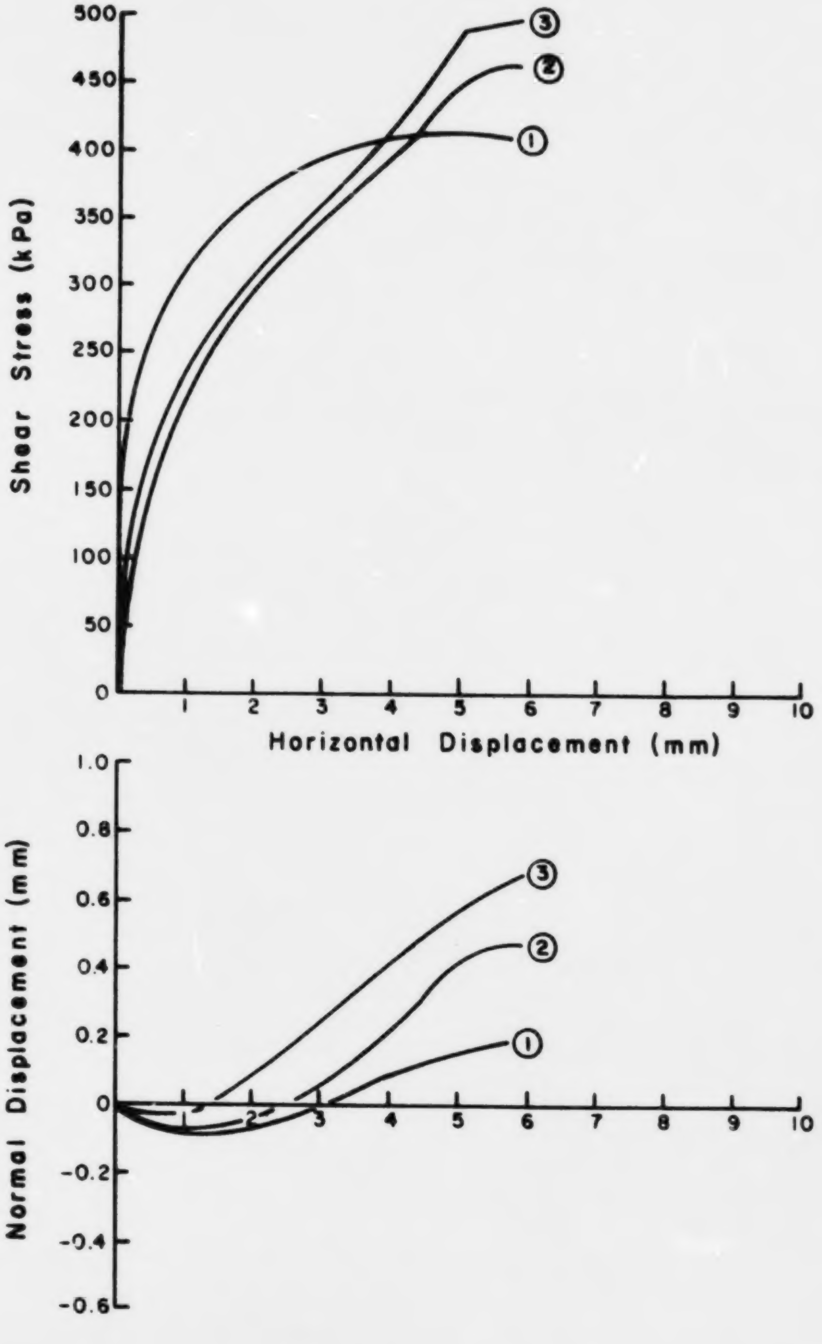
SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville		ACC'T No.
DESIGNED BY:			Direct Shear Test	PROJECT No
DRAWN BY: J.J.	SEPT. 1984	Potash Corporation of Saskatchewan	Roc. B-Slimes	DWG. No. 2 25
CHECKED BY:				
APPROVED BY:			10% Insolubles	SH. of REV.

Effective Normal Stress = 143 kPa



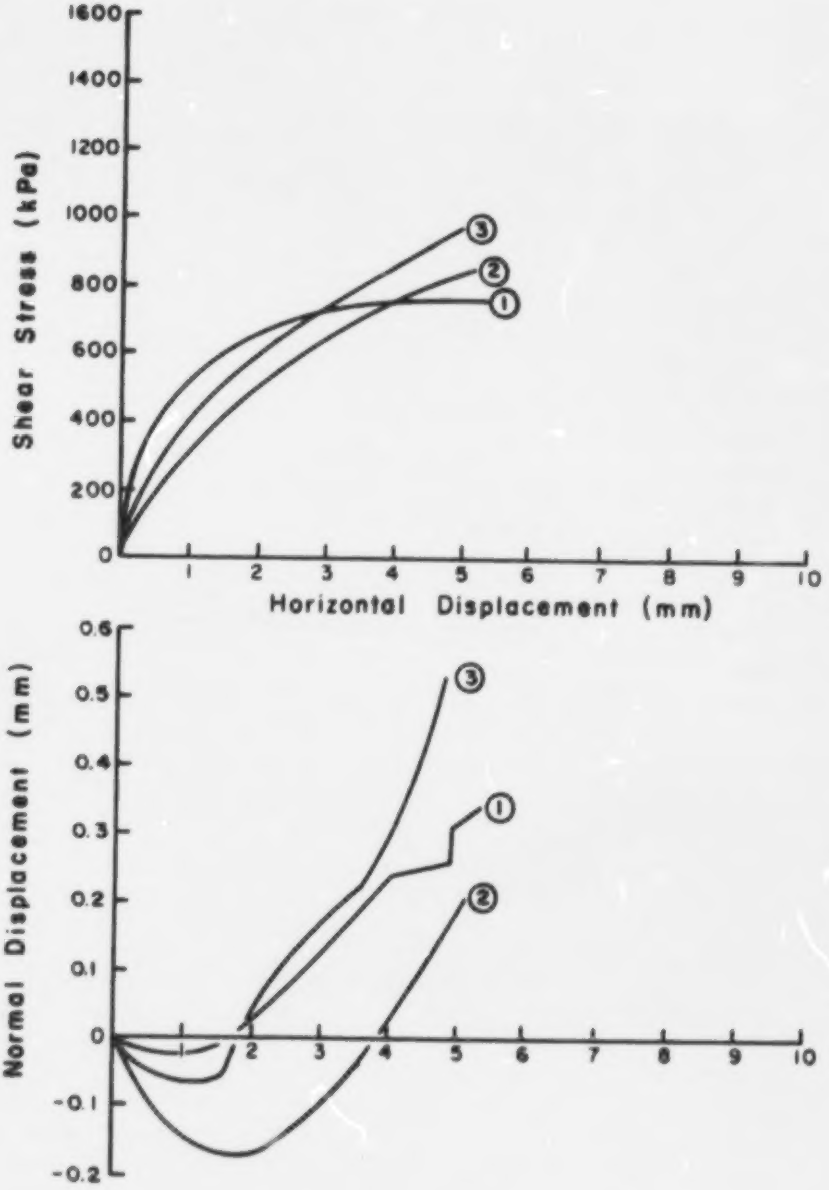
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc. B-Slimes	PROJECT No
DRAWN BY: A.A.	SEPT. 1984		10% Insolubles	DWG. No 2 26
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Normal Stress = 438 kPa

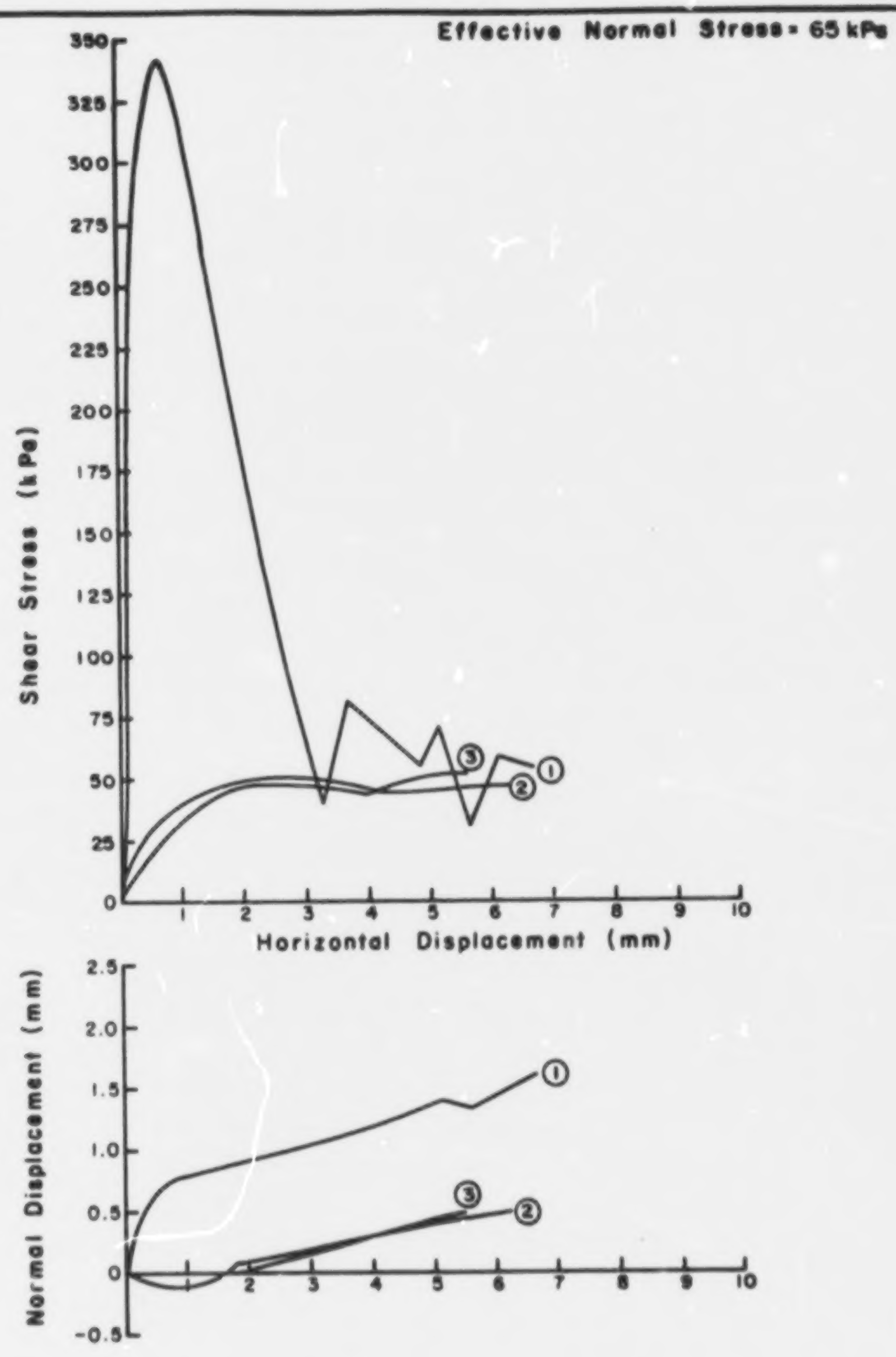


SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc. B-Slimes	PROJECT No
DRAWN BY: L.A.	SEPT, 1984		10% Insolubles	DWG. No. 2 27
CHECKED BY:				SH. of
APPROVED BY:				REV.

Effective Normal Stress = 810 kPa

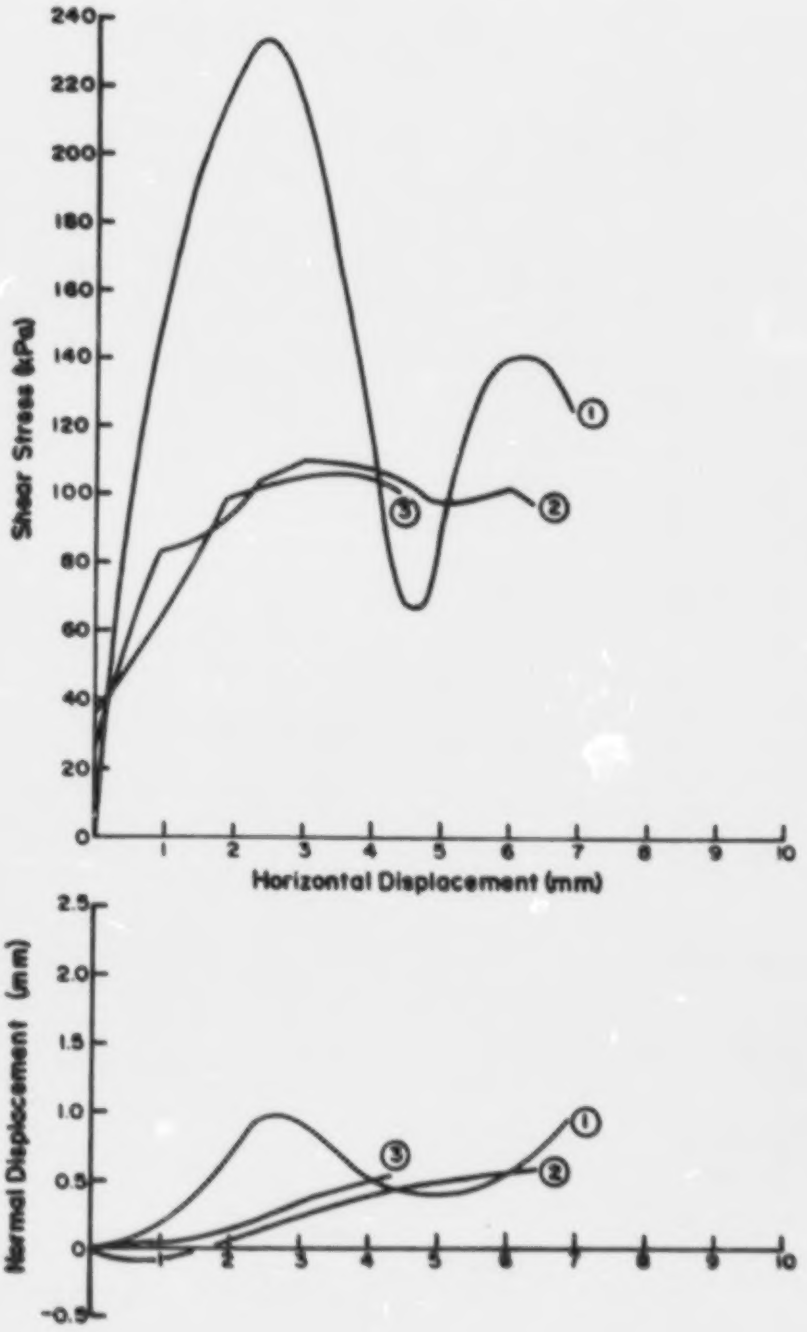


SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville		ACC'T No.
DESIGNED BY:			Direct Shear Test	PROJECT No
DRAWN BY: A.A.	SEPT, 1984	Potash Corporation of Saskatchewan	Roc. B - Slimes	DWG. No 2 28
CHECKED BY:				
APPROVED BY:			10% Insolubles	SH. of REV.



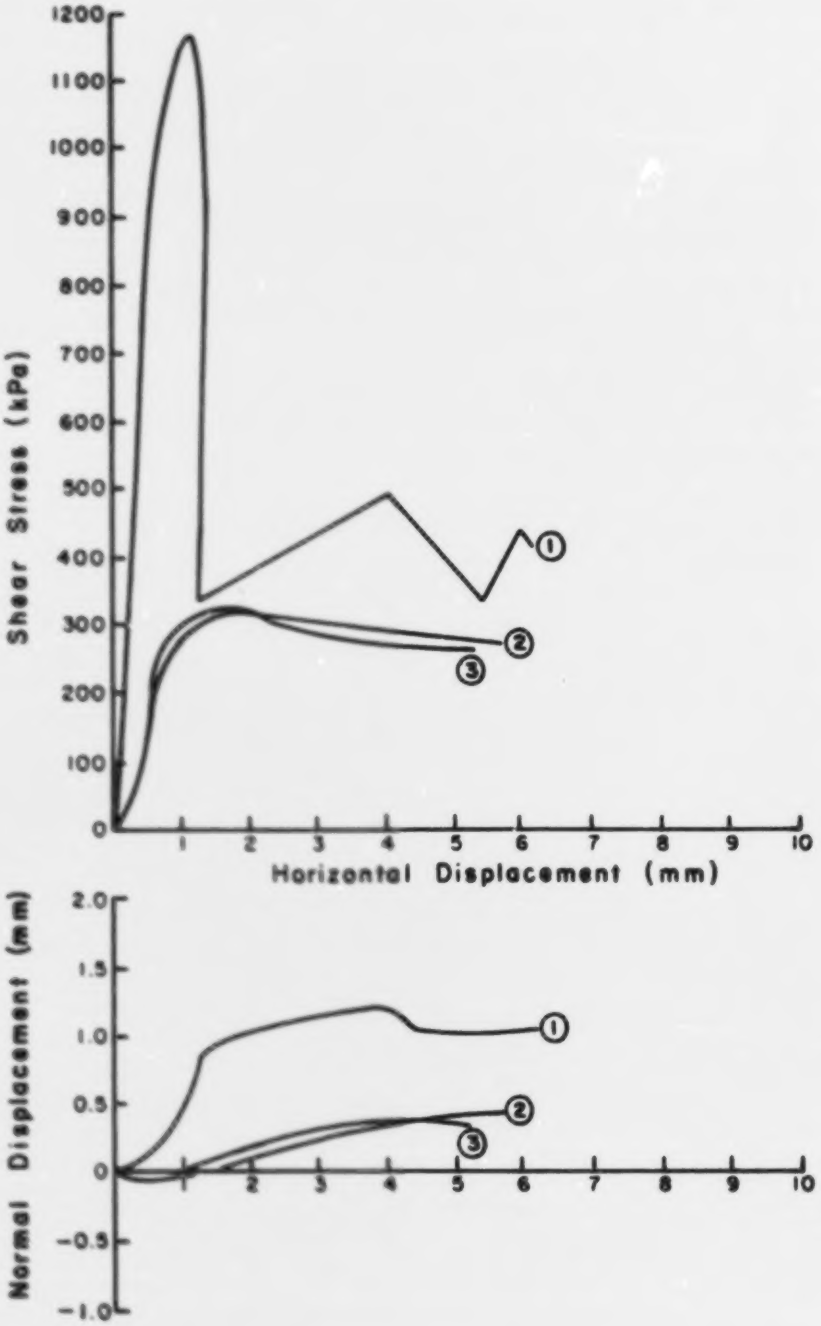
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc. C	PROJECT No.
DRAWN BY: f.R.	SEPT, 1984		Salt Tails	DWG. No 2 29
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 143 kPa



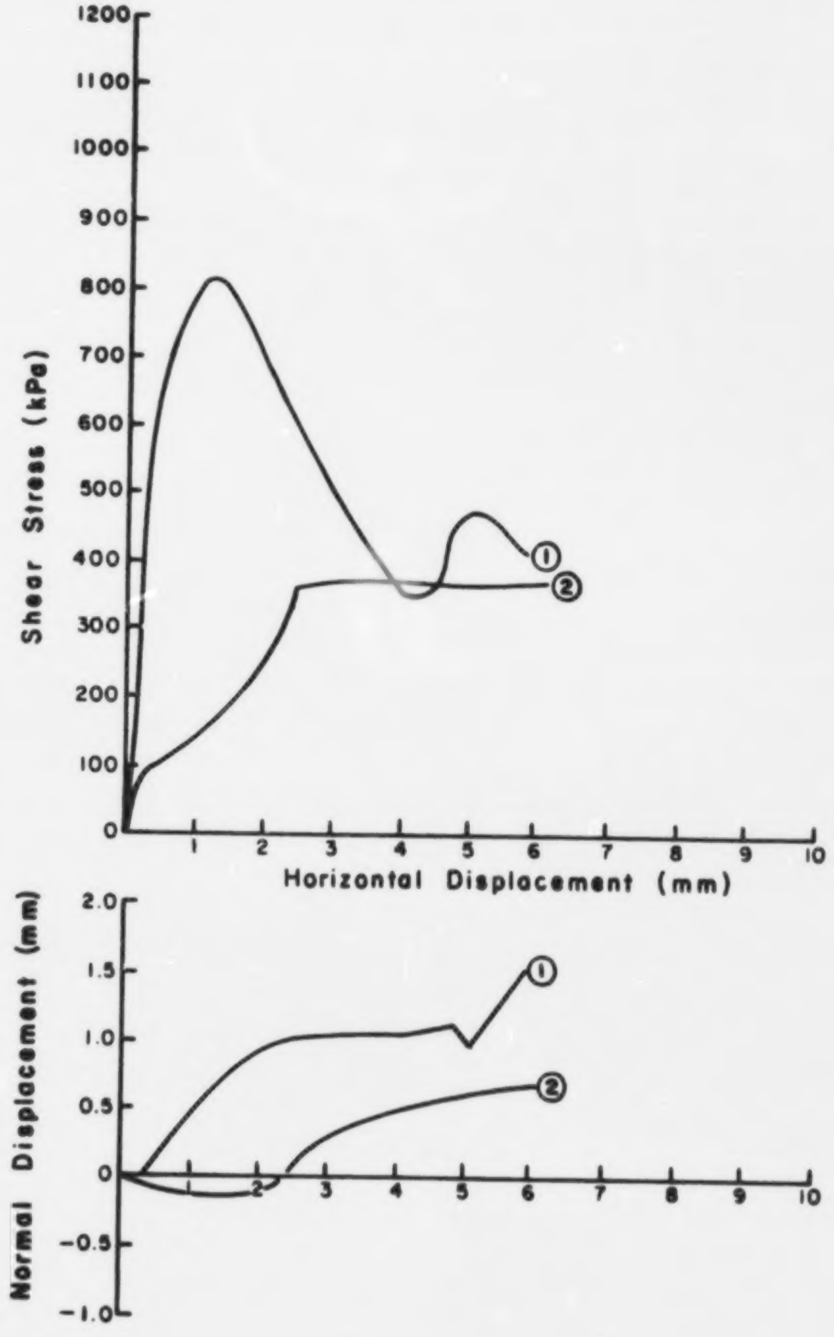
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc. C	PROJECT No
DRAWN BY: ℛ.ℛ.	SEPT. 1984		Salt Tails	DWG. No 2 30
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress=438 kPa



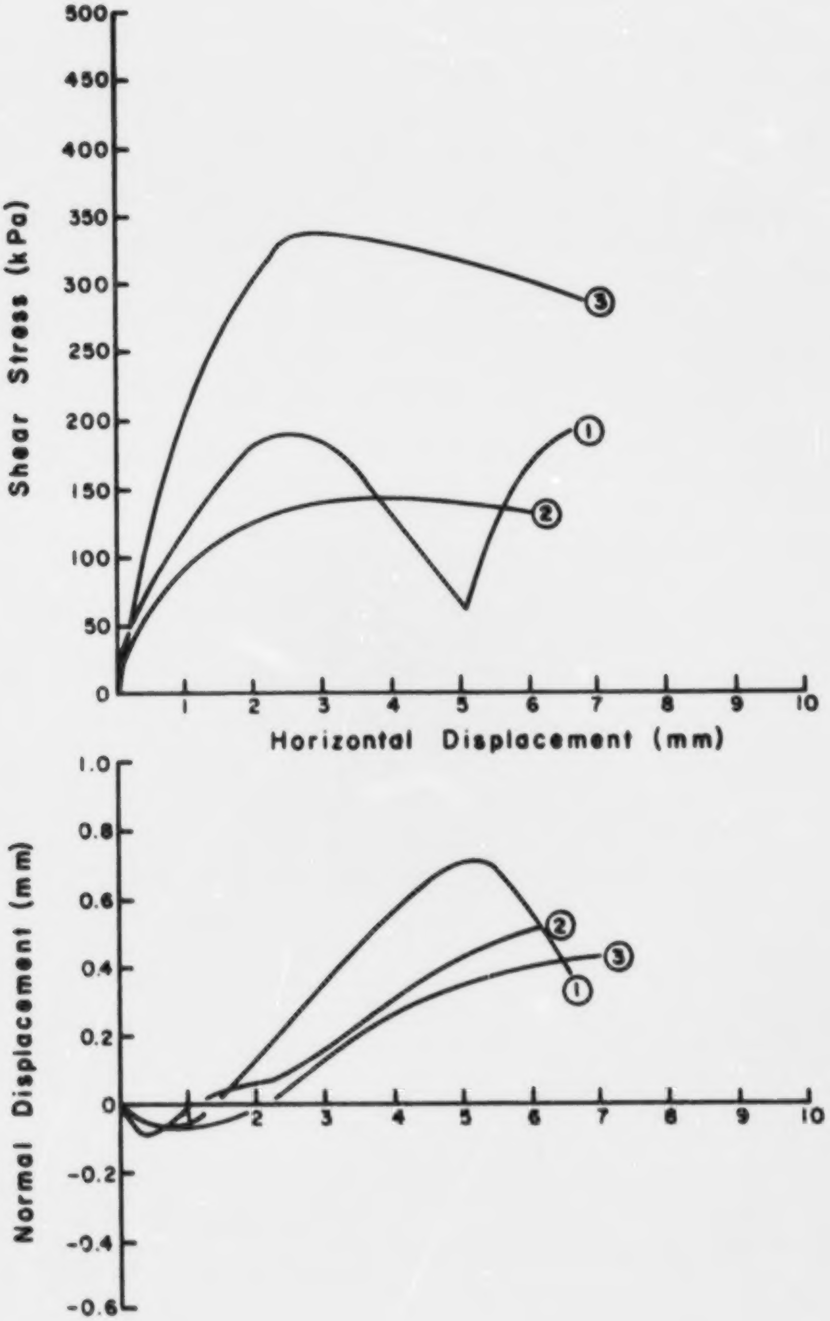
SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville		ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Direct Shear Test	PROJECT No
DRAWN BY: P.H.	SEPT, 1984		Roc. C	DWG. No 2 31
CHECKED BY:				
APPROVED BY:			Salt Tails	SH. of	REV.

Effective Normal Stress = 438 kPa



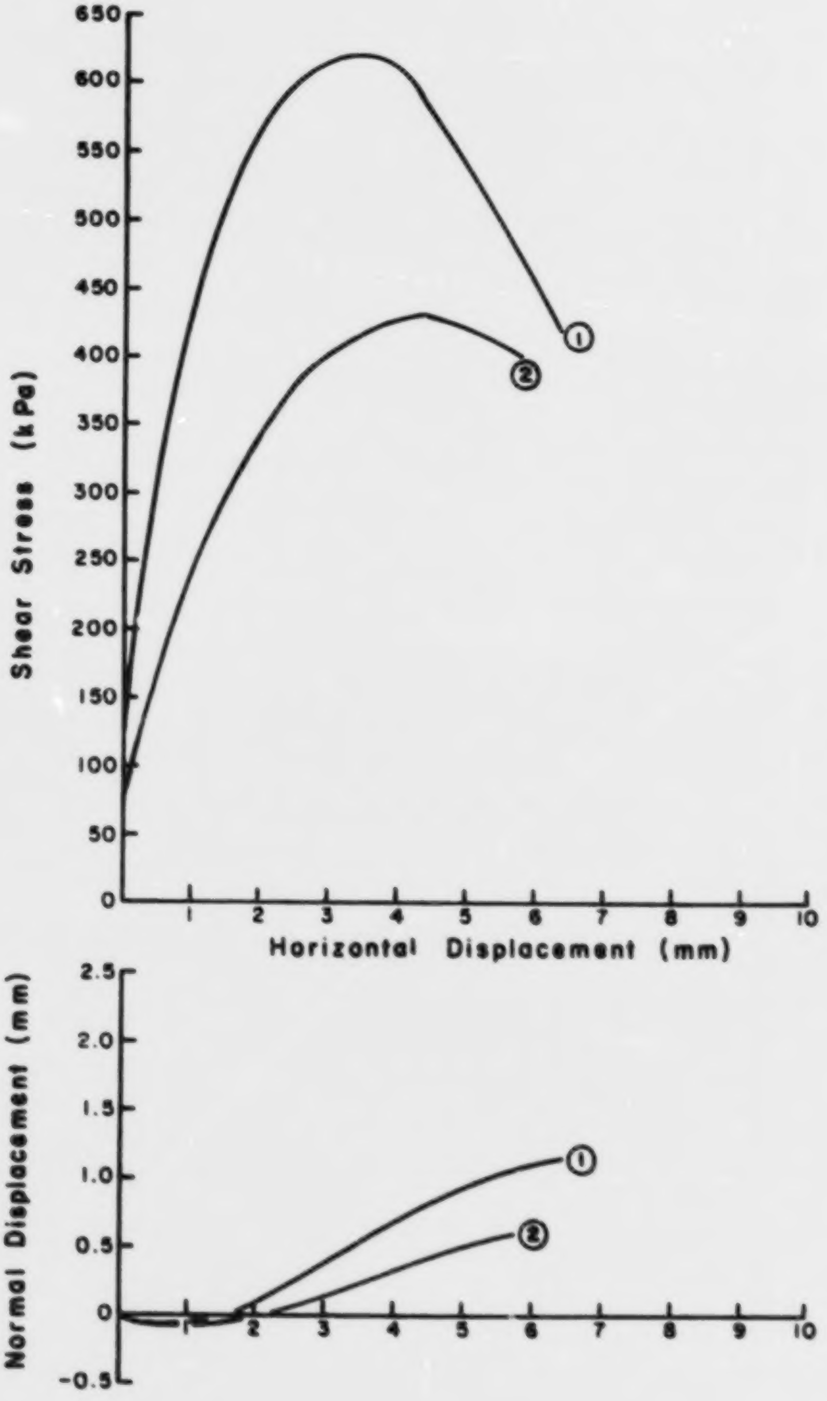
SECTION:		**LOCATION:** Rocanville	**TITLE:** Direct Shear Test Roc. C Salt Tails	**M.C.C. No.**
SCALE:	**DATE**			**ACC'T No.**
DESIGNED BY:		Potash Corporation of Saskatchewan		**PROJECT No**
DRAWN BY:	SEPT, 1984			**DWG. No.** 2 32
CHECKED BY:				**SH.** of **REV.**
APPROVED BY:				

Effective Normal Stress = 438 kPa



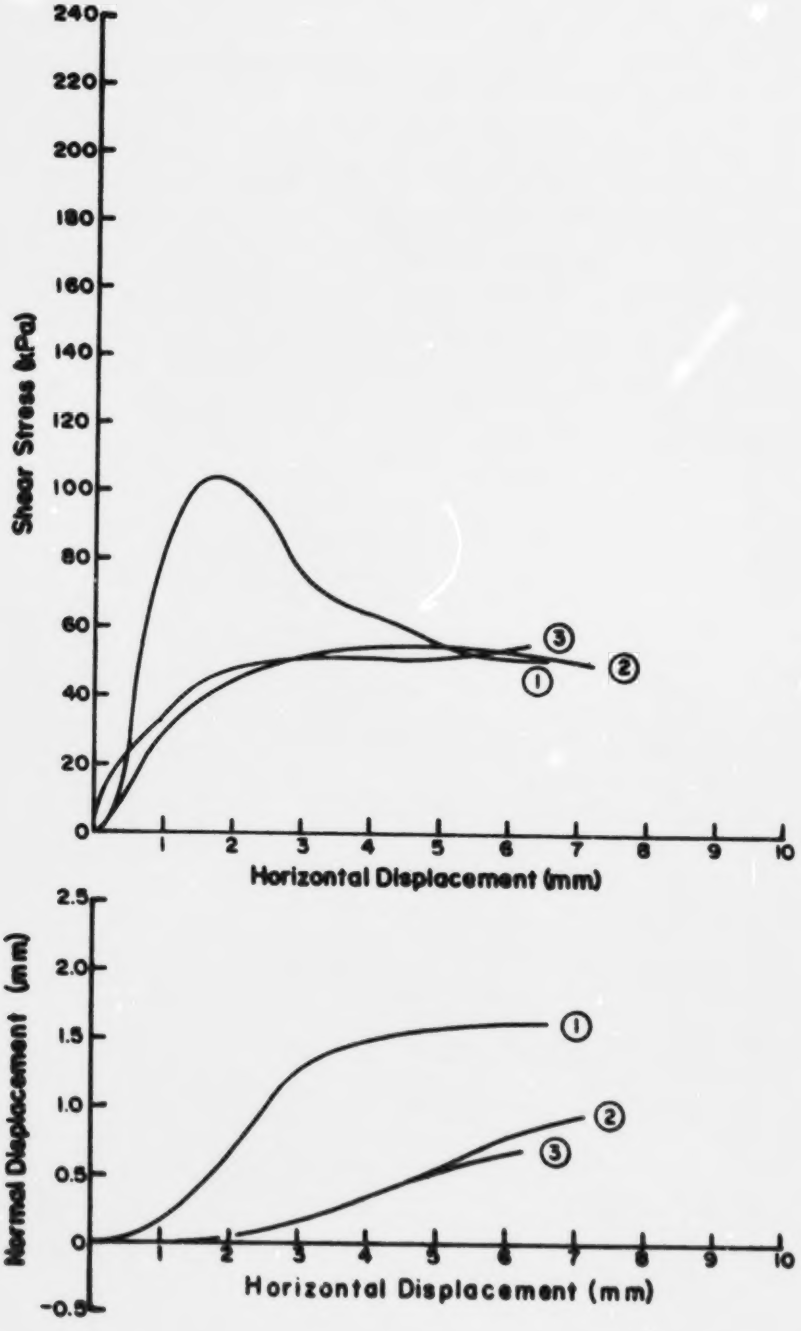
SECTION:		LOCATION:	TITLE:	M.C.C. No.	
SCALE:	DATE	Rocanville		ACC'T No.	
DESIGNED BY:		Potash Corporation of Saskatchewan	Direct Shear Test	PROJECT No	
DRAWN BY: A.A.	SEPT, 1984		Roc. C	DWG. No. 2	33
CHECKED BY:			Salt Tails		
APPROVED BY:				SH. of	REV.

Effective Normal Stress = 562 kPa



SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:			Direct Shear Test	PROJECT No.
DRAWN BY:	SEPT, 1984	Potash Corporation of Saskatchewan	Roc. C	DWG. No. 2 34
CHECKED BY:			Salt Tails	SH. of REV.
APPROVED BY:				

Effective Normal Stress = 65 kPa



SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY: LG	SEPT. 1984
CHECKED BY:	
APPROVED BY:	

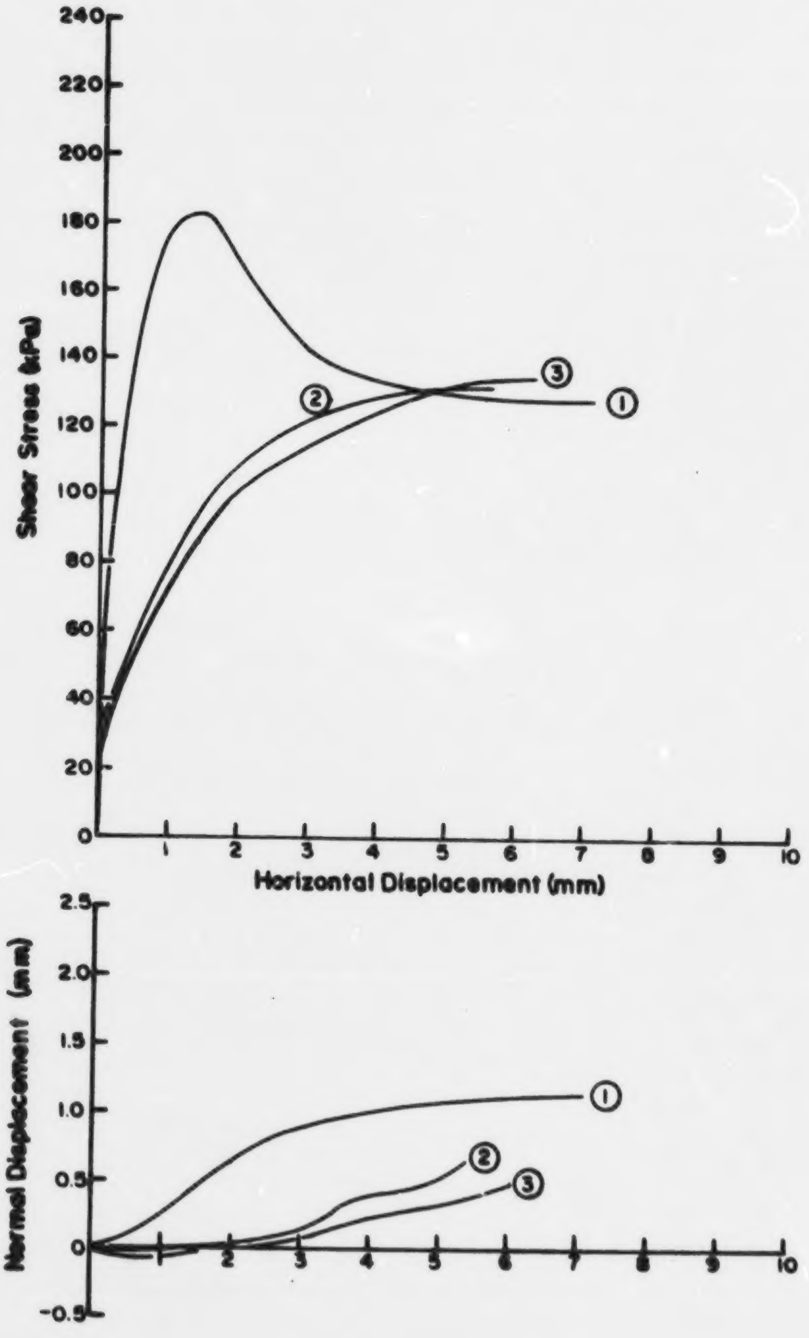
LOCATION: Rocanville

Potash Corporation of Saskatchewan

TITLE:
Direct Shear Test
Roc D-Salt
32% Insolubles

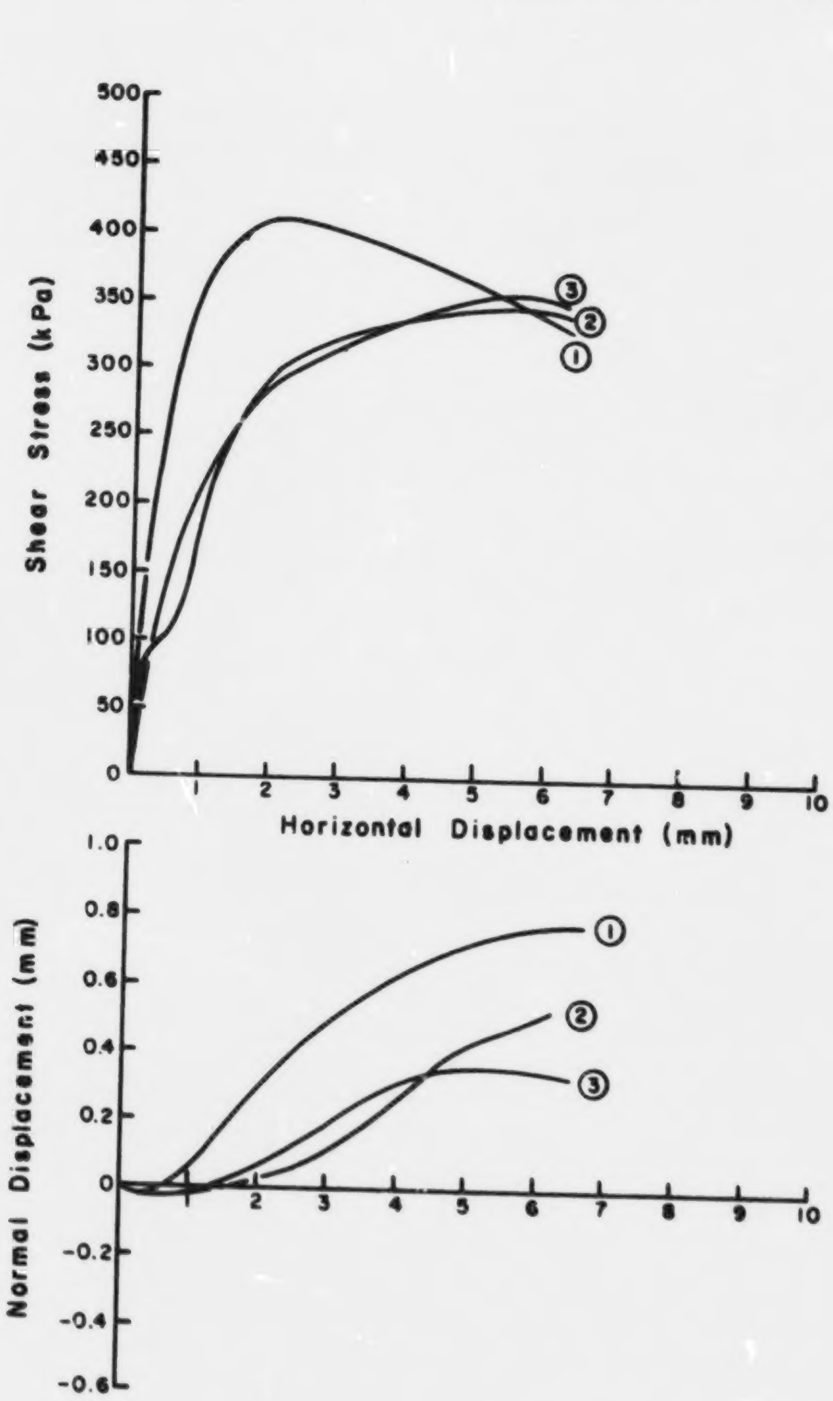
M.C.C. No.
ACC'T No.
PROJECT No.
DWG. No. 2 35
SH. of
REV.

Effective Normal Stress = 143 kPa



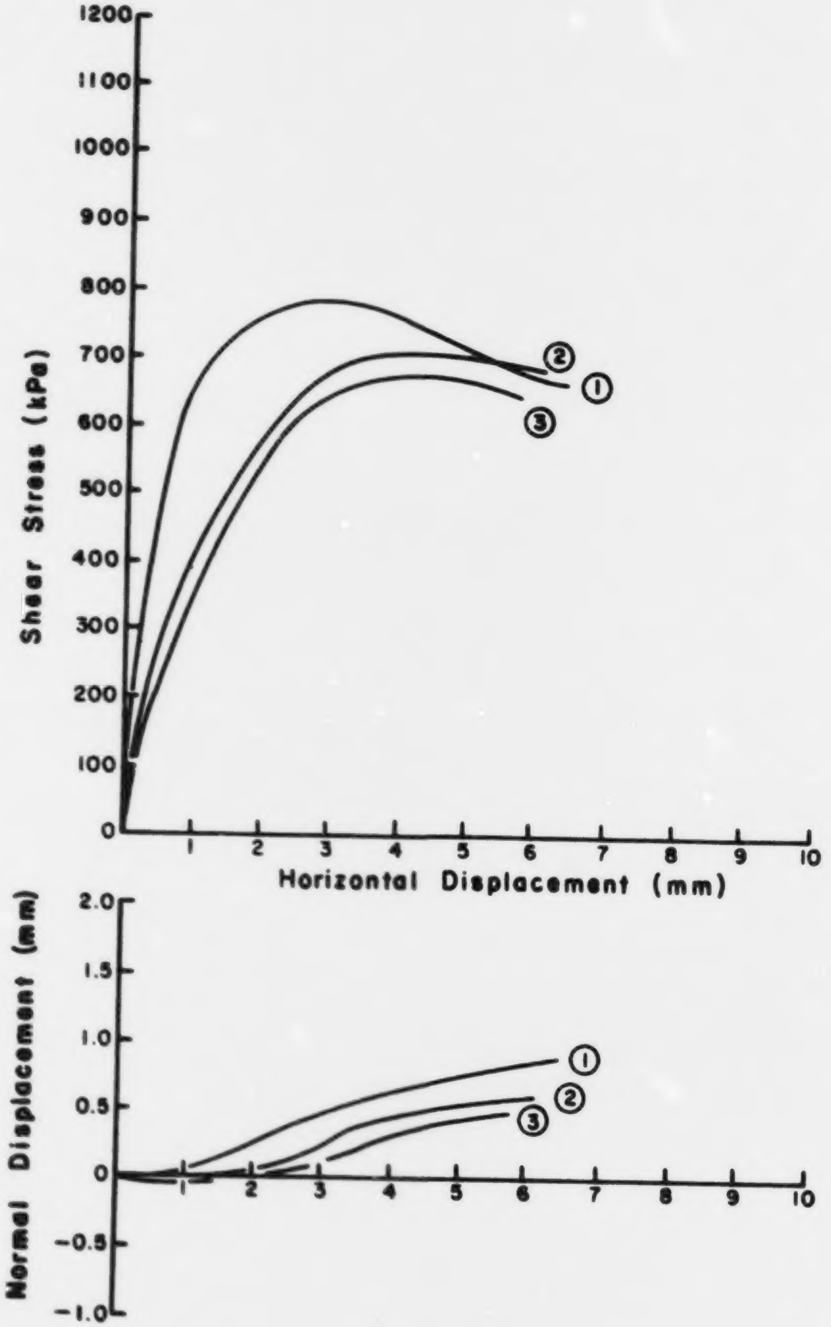
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Roc D-Salt	PROJECT No
DRAWN BY: LS	SEPT. 1984		32 % Insolubles	DWG. No 2 36
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 438 kPa



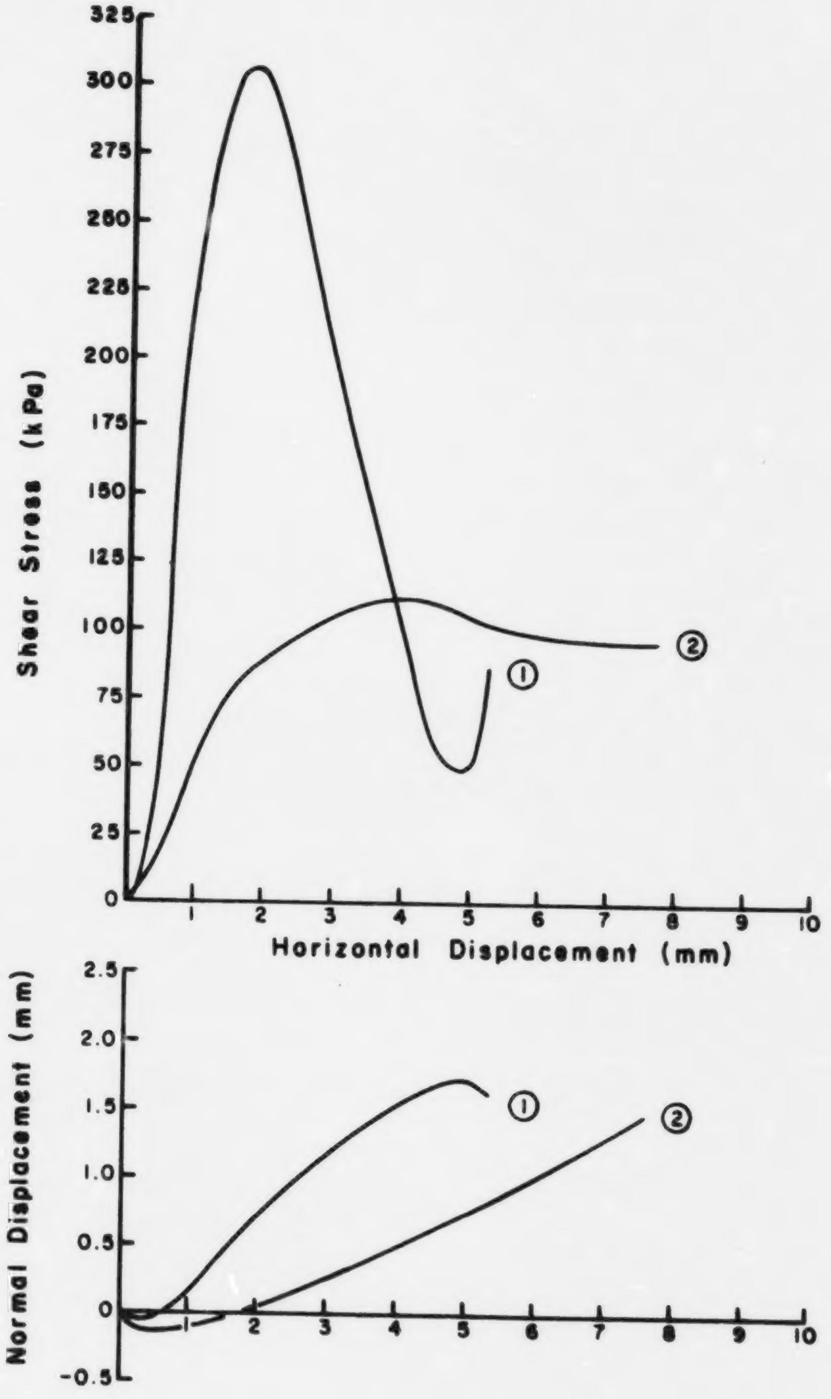
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test	ACC'T No.
DESIGNED BY:			Roc D-Salt	PROJECT No
DRAWN BY:	SEPT, 1984	Potash Corporation of Saskatchewan	32% Insolubles	DWG. No 2 37
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 810 kPa



SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Roc D-Salt 32% Insolubles	ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY: LS	SEPT. 1984	Potash Corporation of Saskatchewan		DWG. No. 2 38
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Normal Stress = 70 kPa



SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY: LS	SEPT, 1984
CHECKED BY:	
APPROVED BY:	

LOCATION: Rocanville

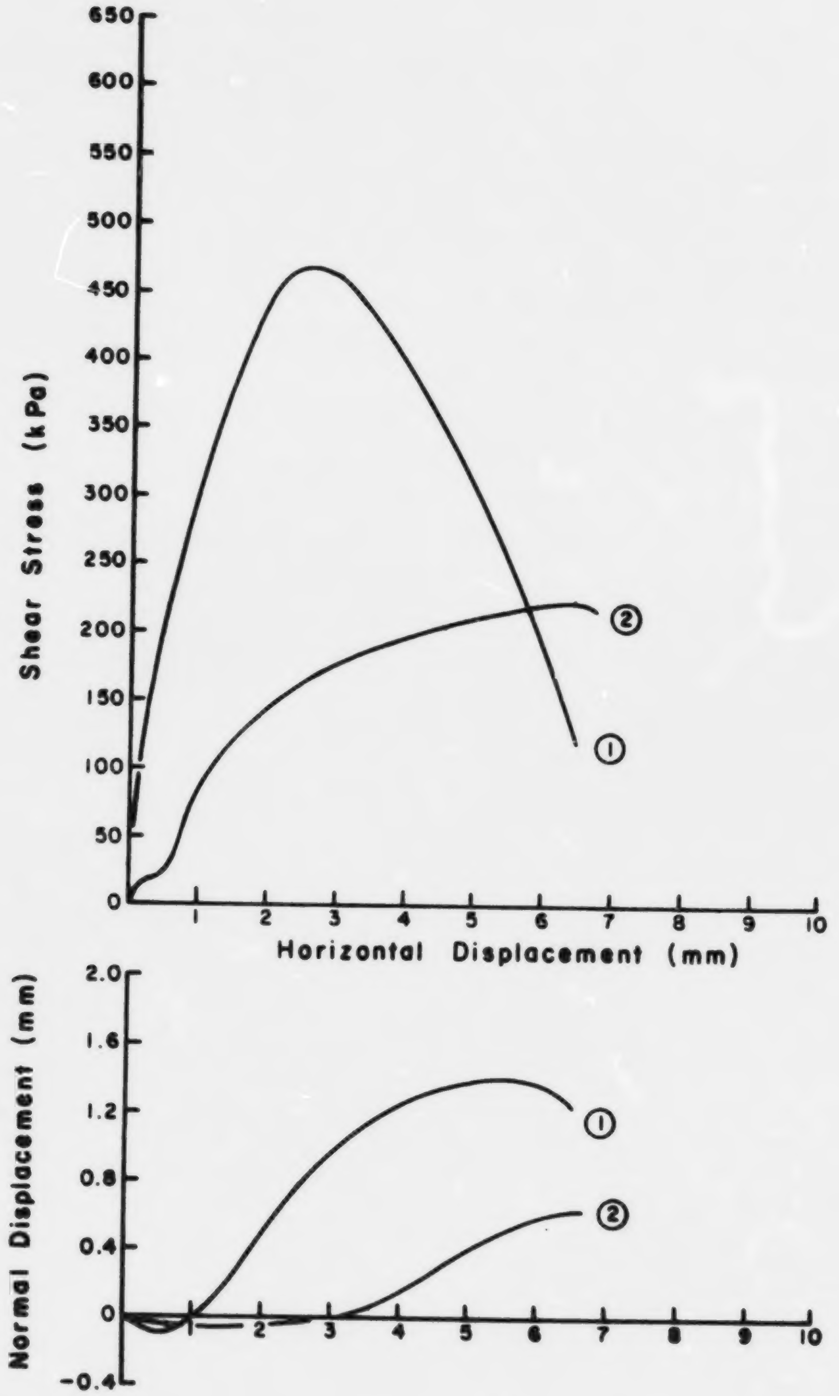
Potash Corporation of Saskatchewan

TITLE:

Direct Shear Test
Roc E-Salt
19% Insolubles

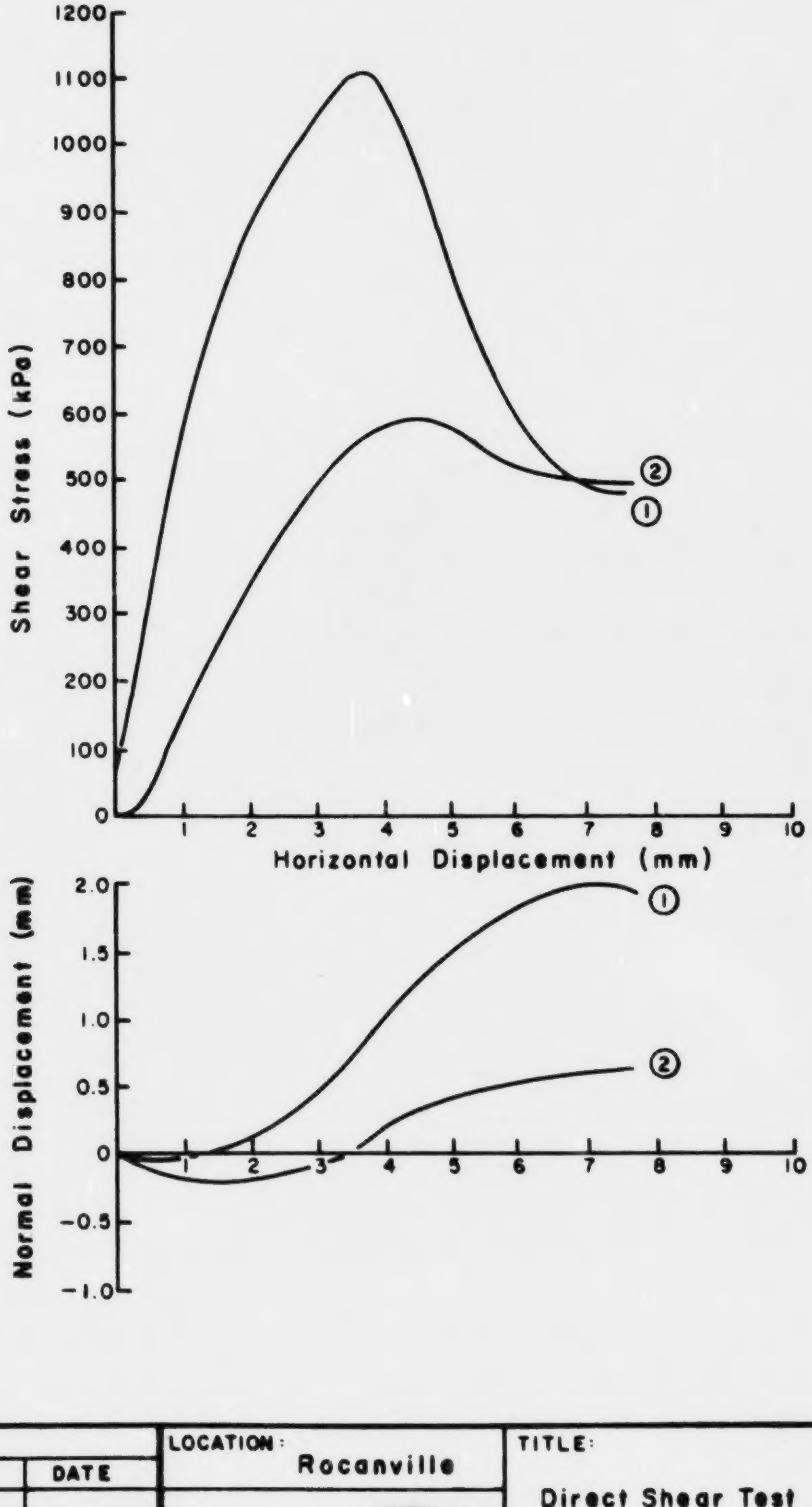
M.C.C. No.	
ACC'T No.	
PROJECT No.	
DWG. No. 2	39
SH. of	REV.

Effective Normal Stress = 150 kPa



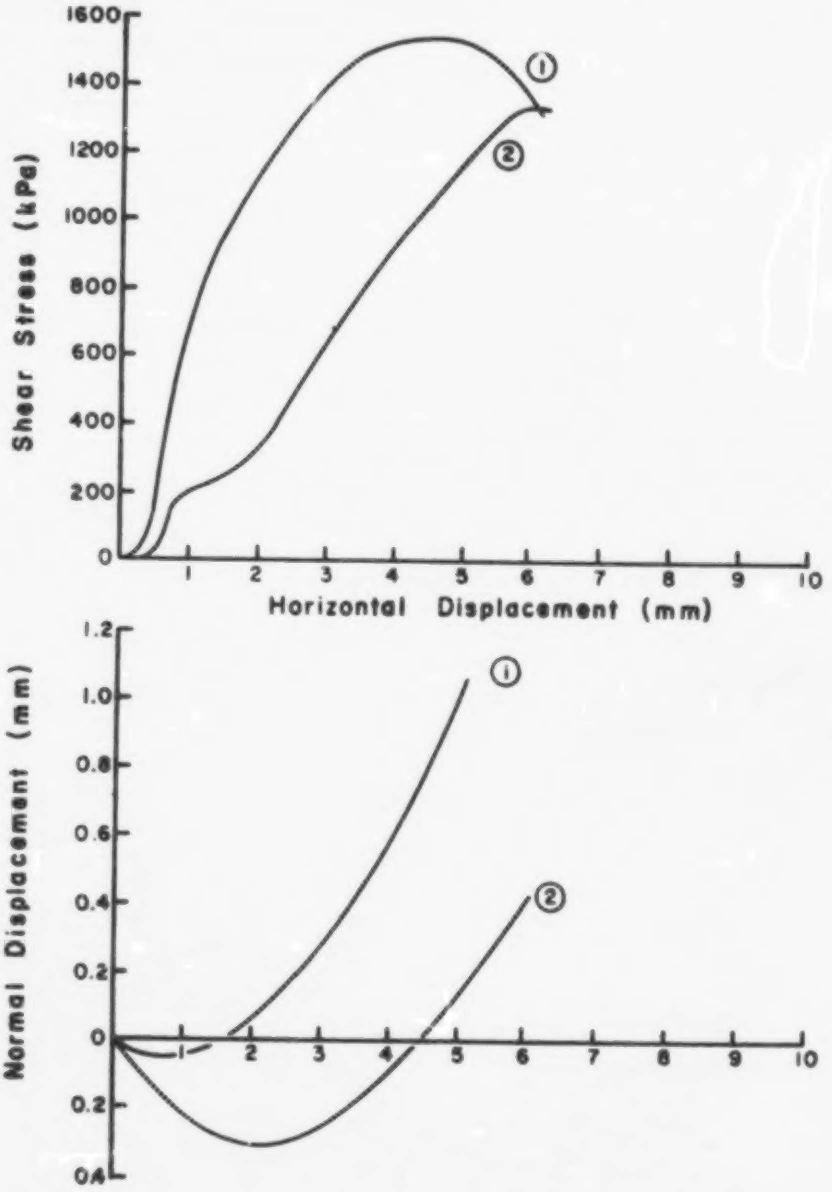
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Roc E – Salt 19 % Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: LS	SEPT, 1984			DWG. No. 2 40
CHECKED BY:				SH. of REV.
APPROVED BY:				

Effective Normal Stress = 450 kPa



SECTION:		LOCATION: Rocanville	TITLE: Direct Shear Test Roc E – Salt 19 % Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: LS	SEPT, 1984			DWG. No. 2 41
CHECKED BY:				SH. of
APPROVED BY:				REV.

Effective Normal Stress = 800 kPa



SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Direct Shear Test Roc E-Salt 19 % Insolubles	ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY:	SEPT, 1984	Potash Corporation of Saskatchewan		DWG. No. 2 42
CHECKED BY:				
APPROVED BY:				SH. of REV.

APPENDIX A
SECTION 3

TRIAXIAL TEST DATA

MOHR-COULOMB FAILURE ENVELOPES

Triaxial Tests

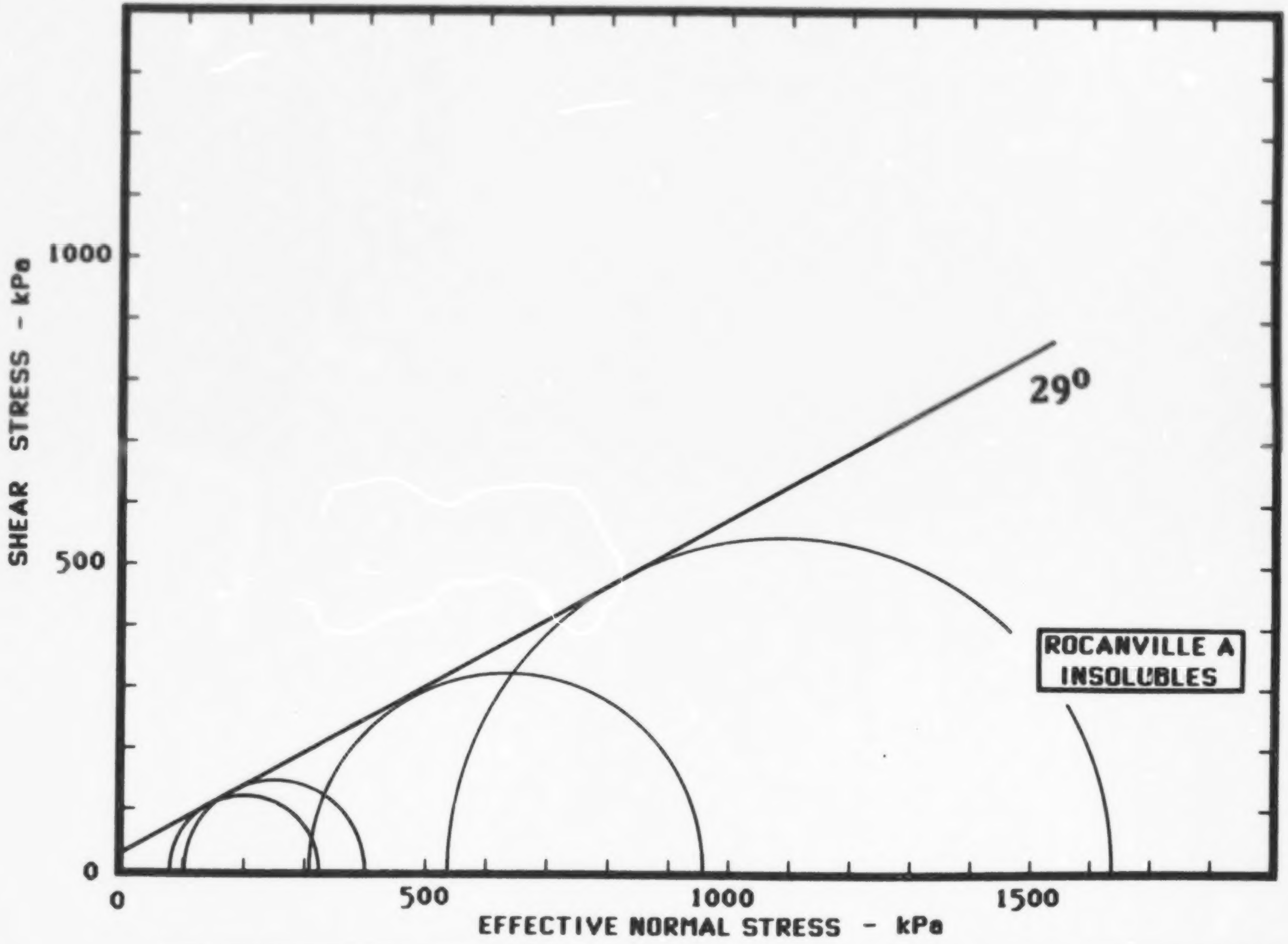


Figure A-3.1 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - ROCANVILLE A

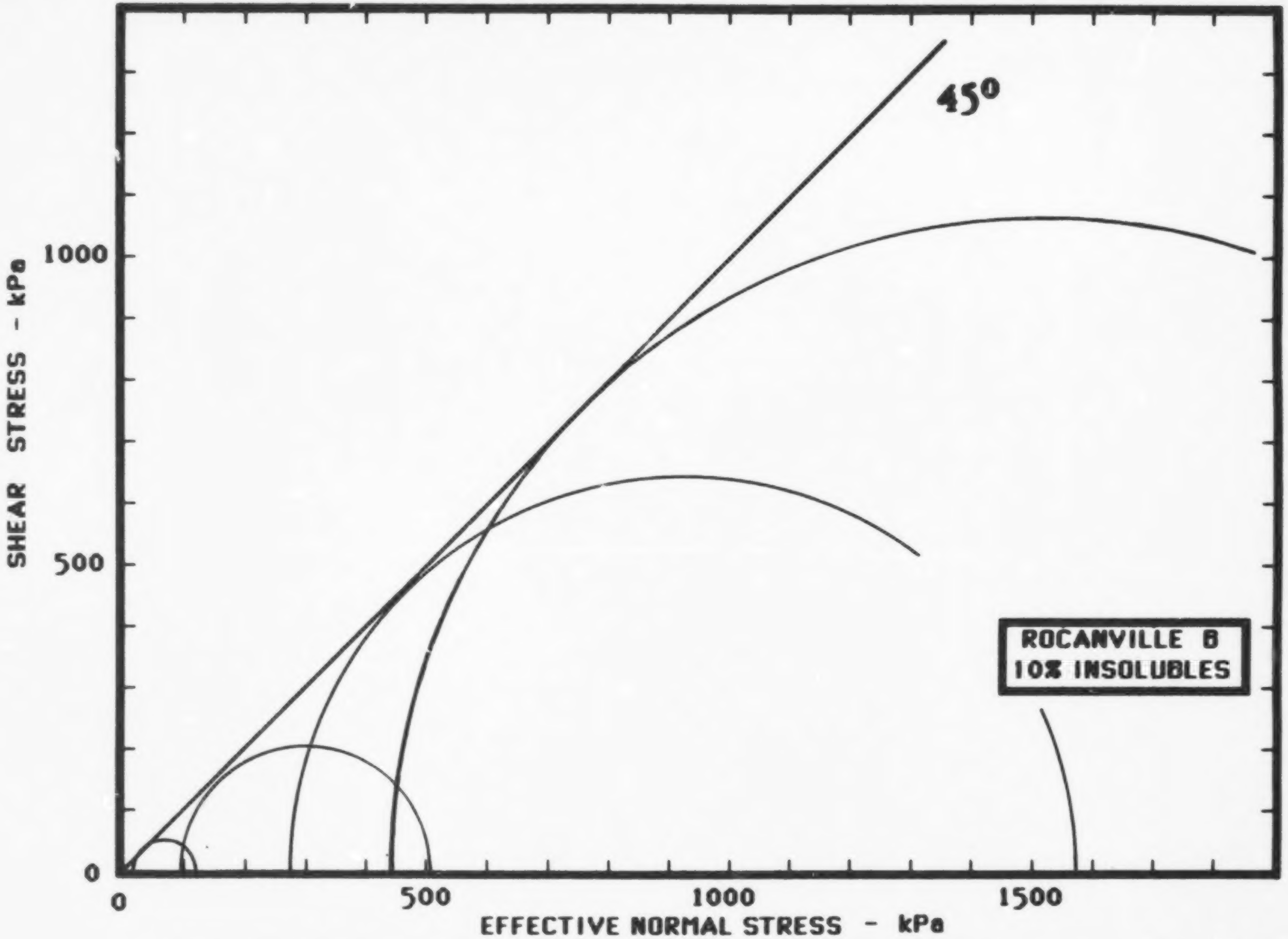


Figure A-3.2 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - ROCANVILLE B

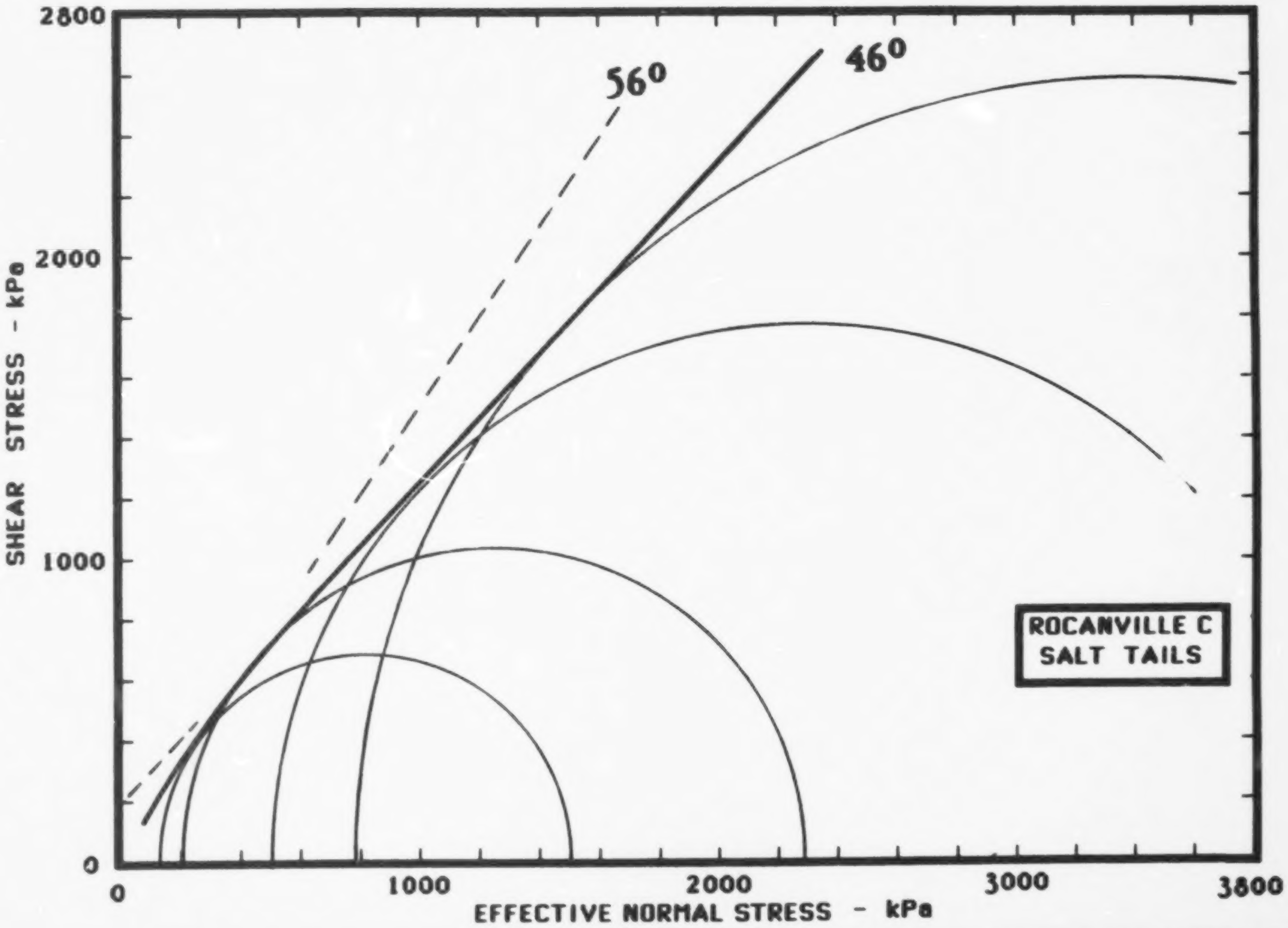


Figure A-3.3 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - ROCANVILLE C

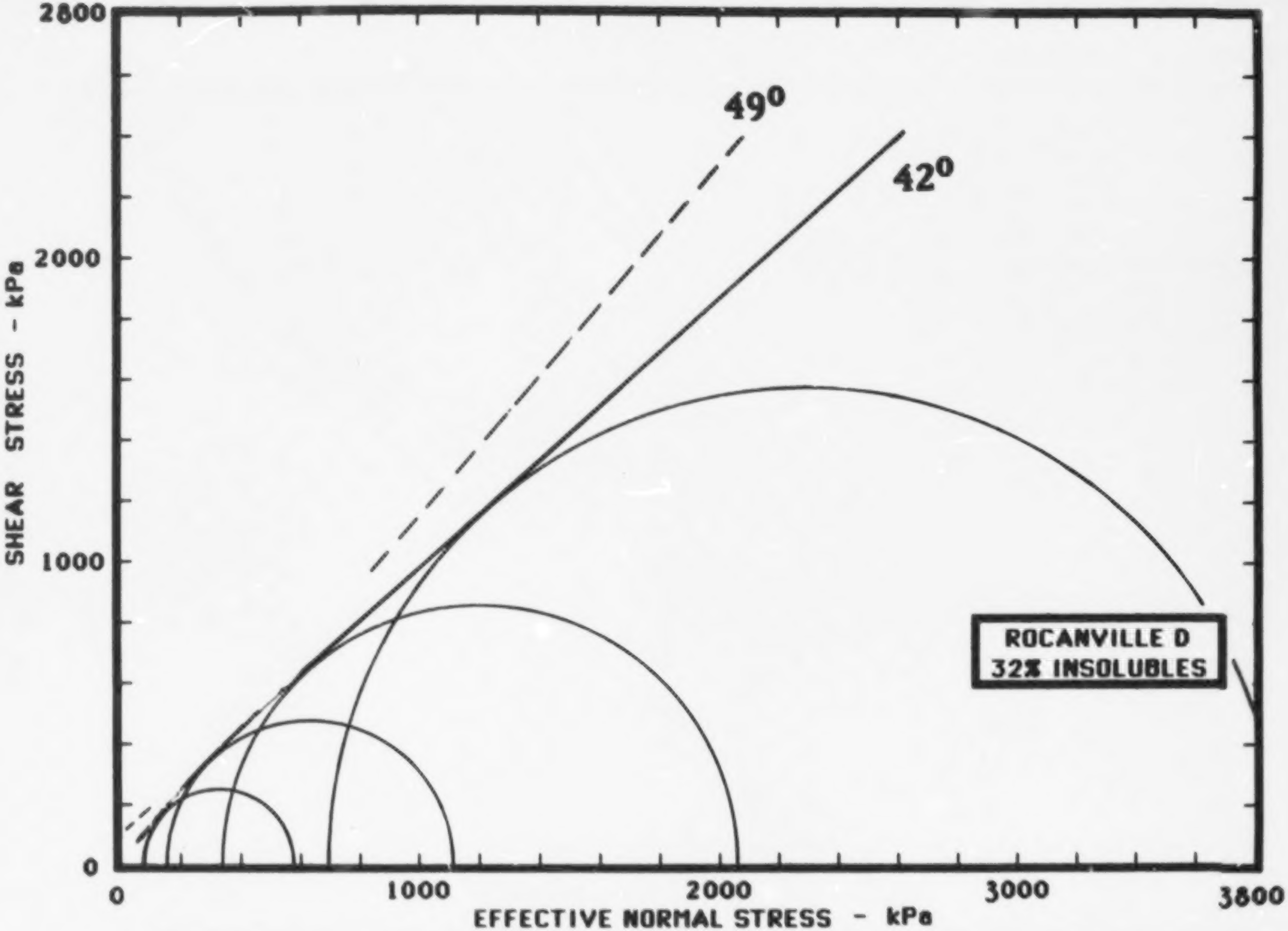


Figure A-3.4 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - ROCANVILLE D

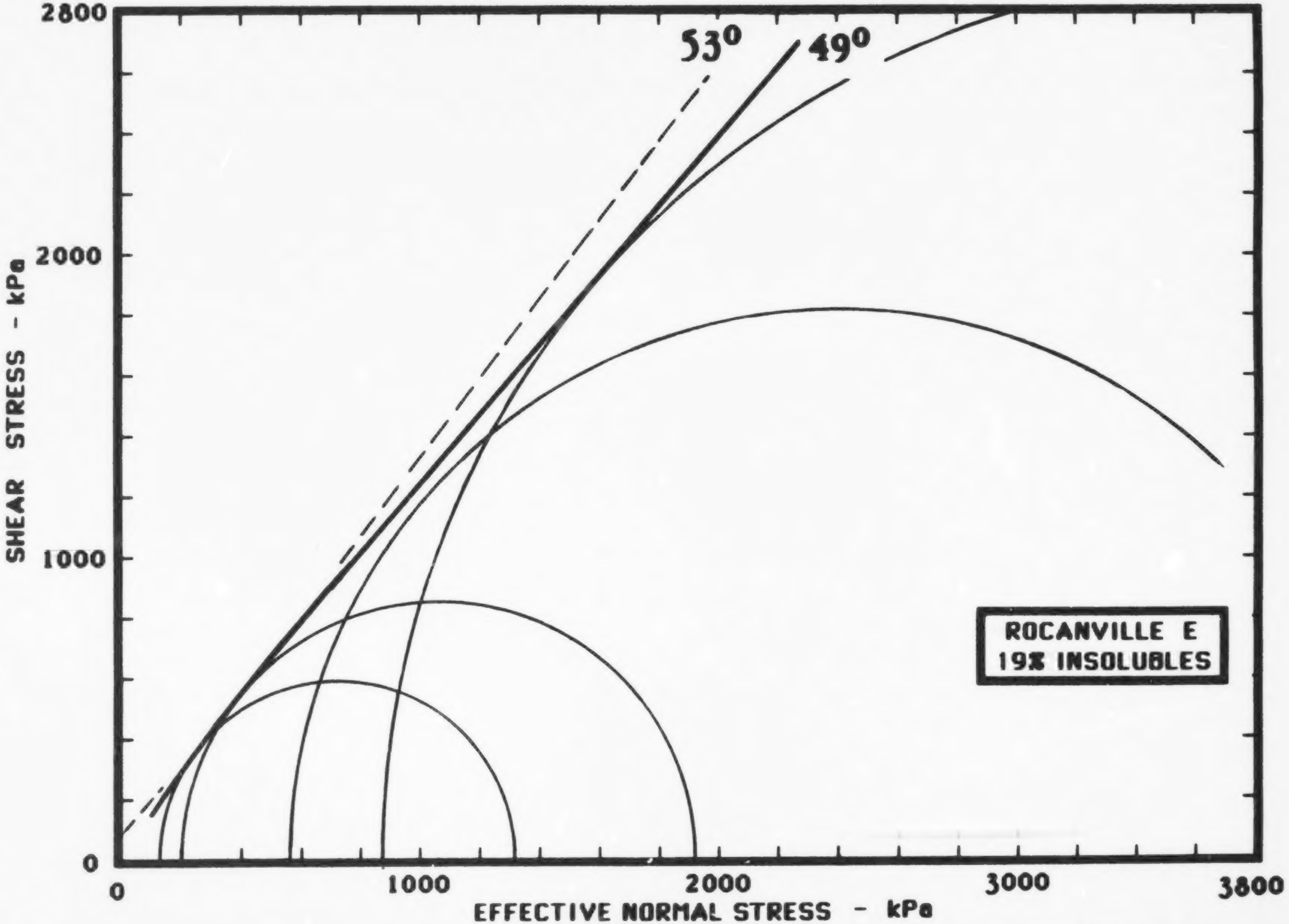


Figure A-3.5 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - ROCANVILLE E

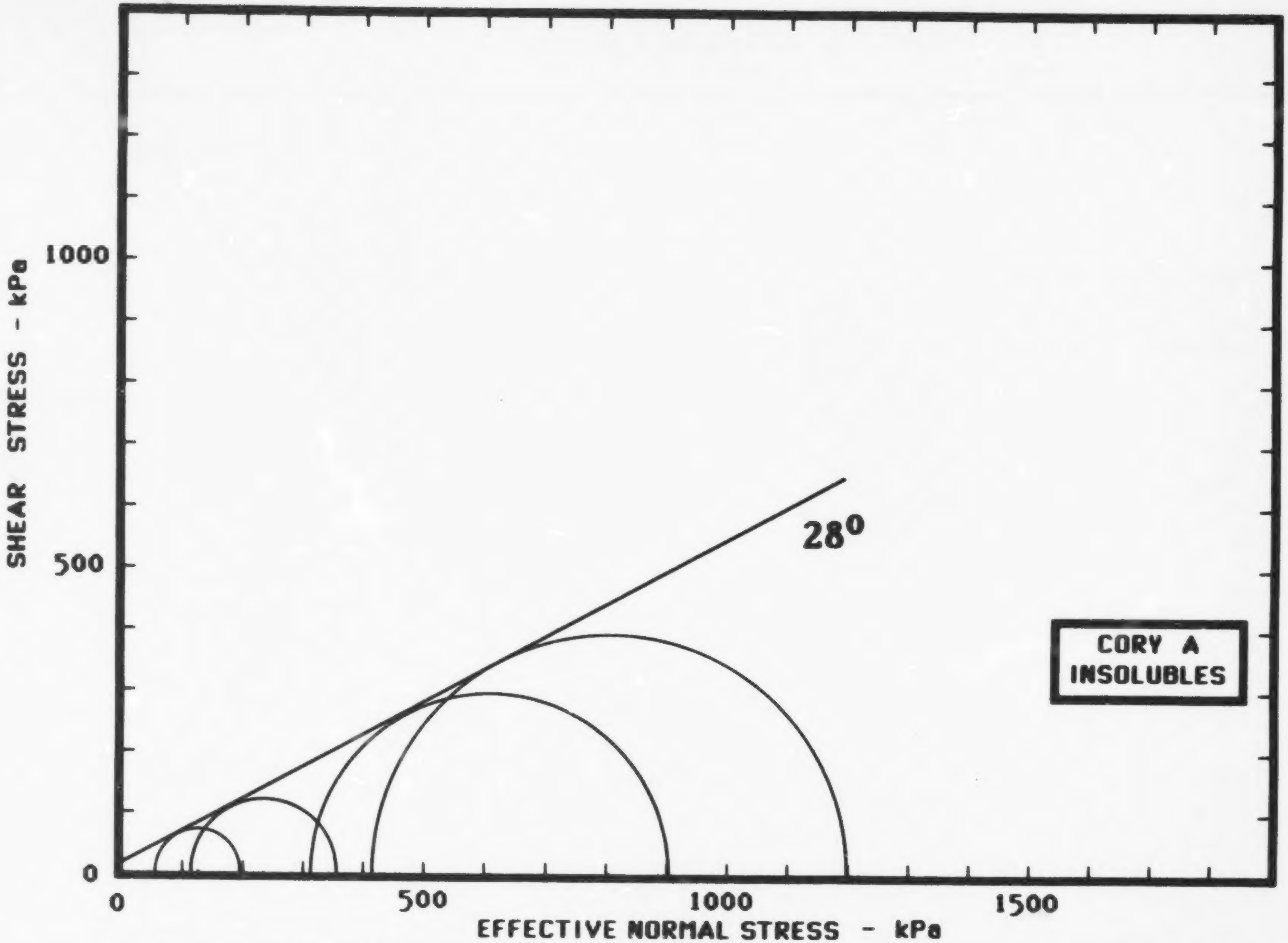


Figure A-3.6 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY A

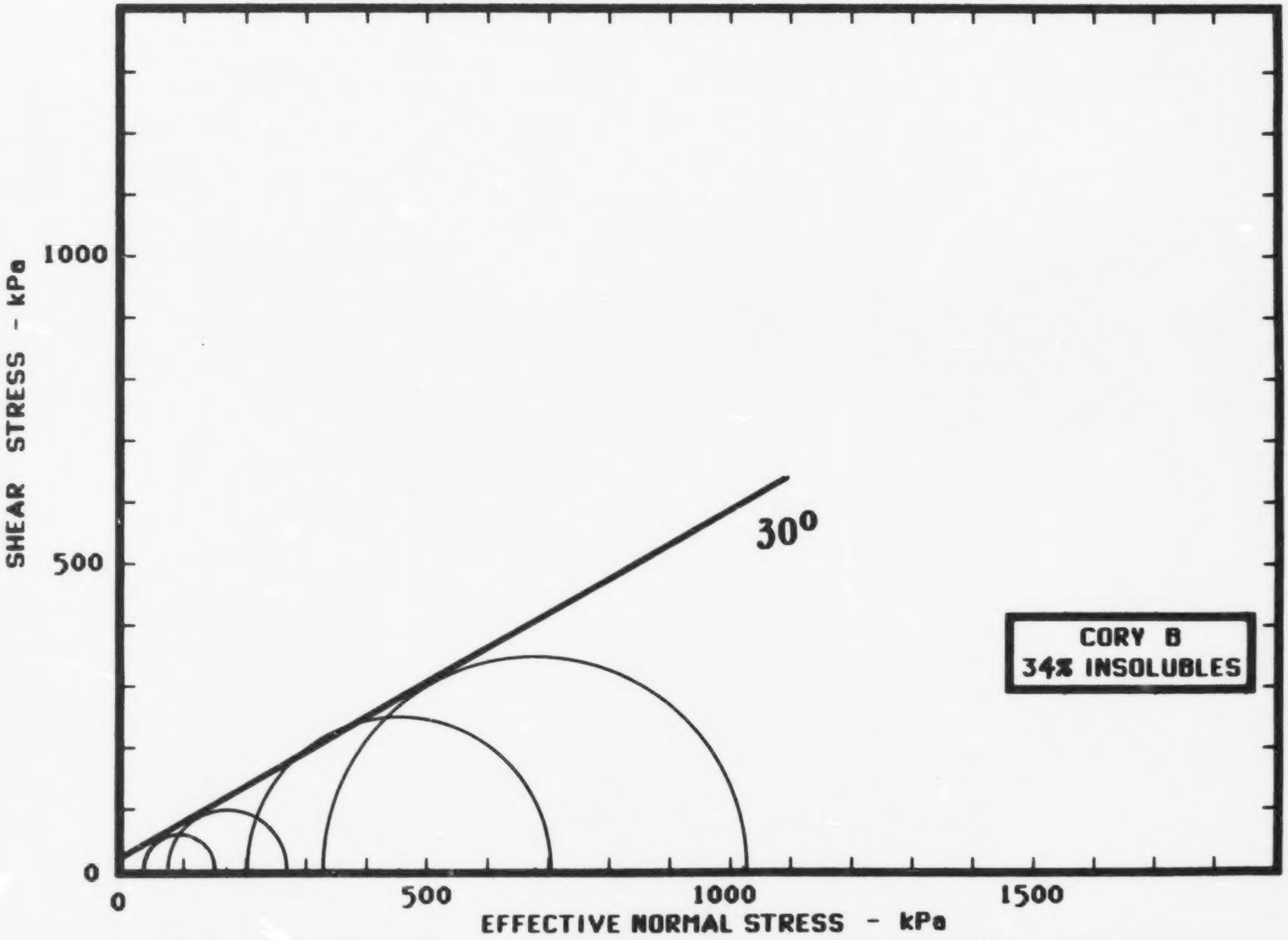


Figure A-3.7 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY B

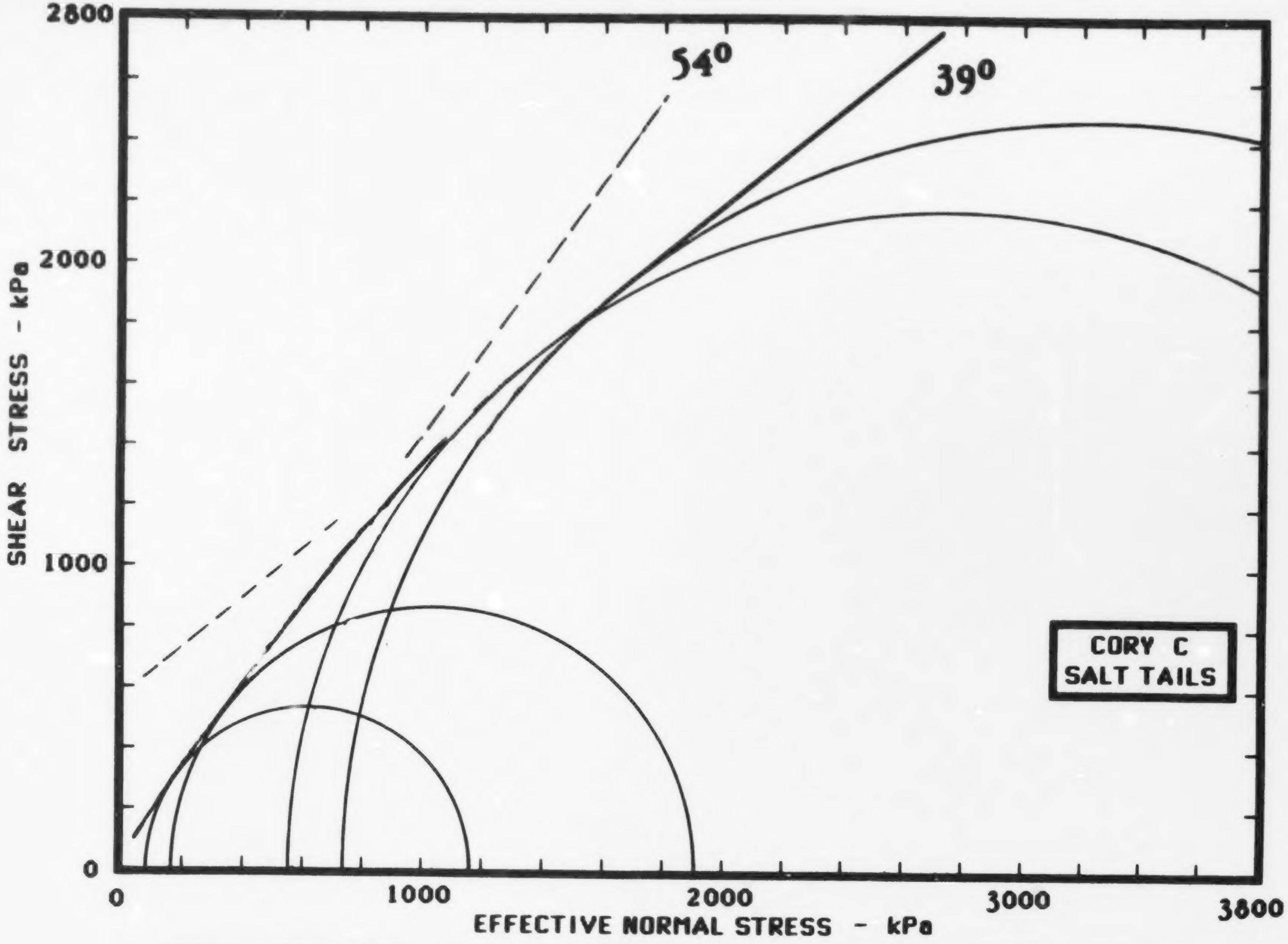


Figure A-3.8 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY C

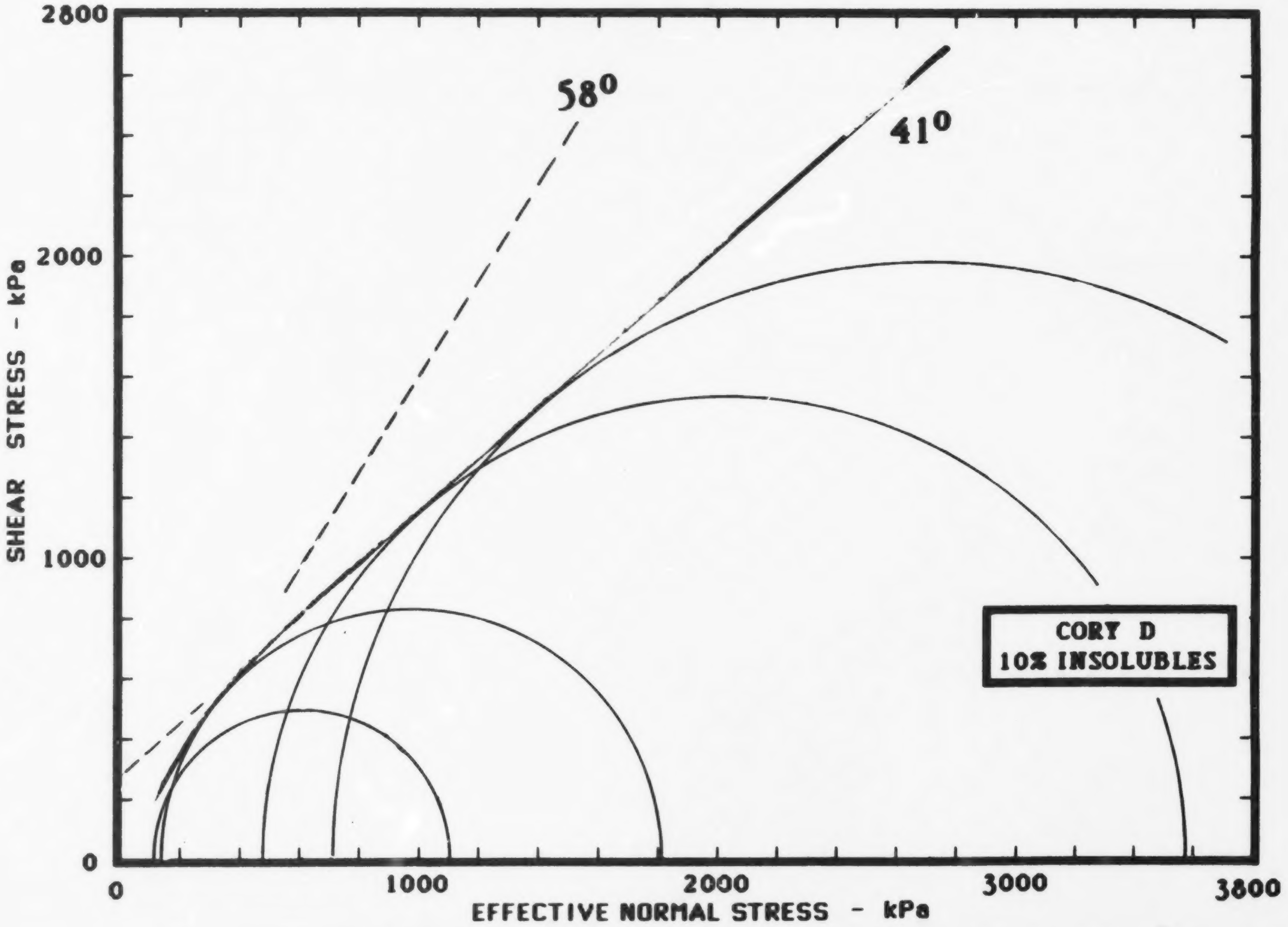


Figure A-3.9 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY D

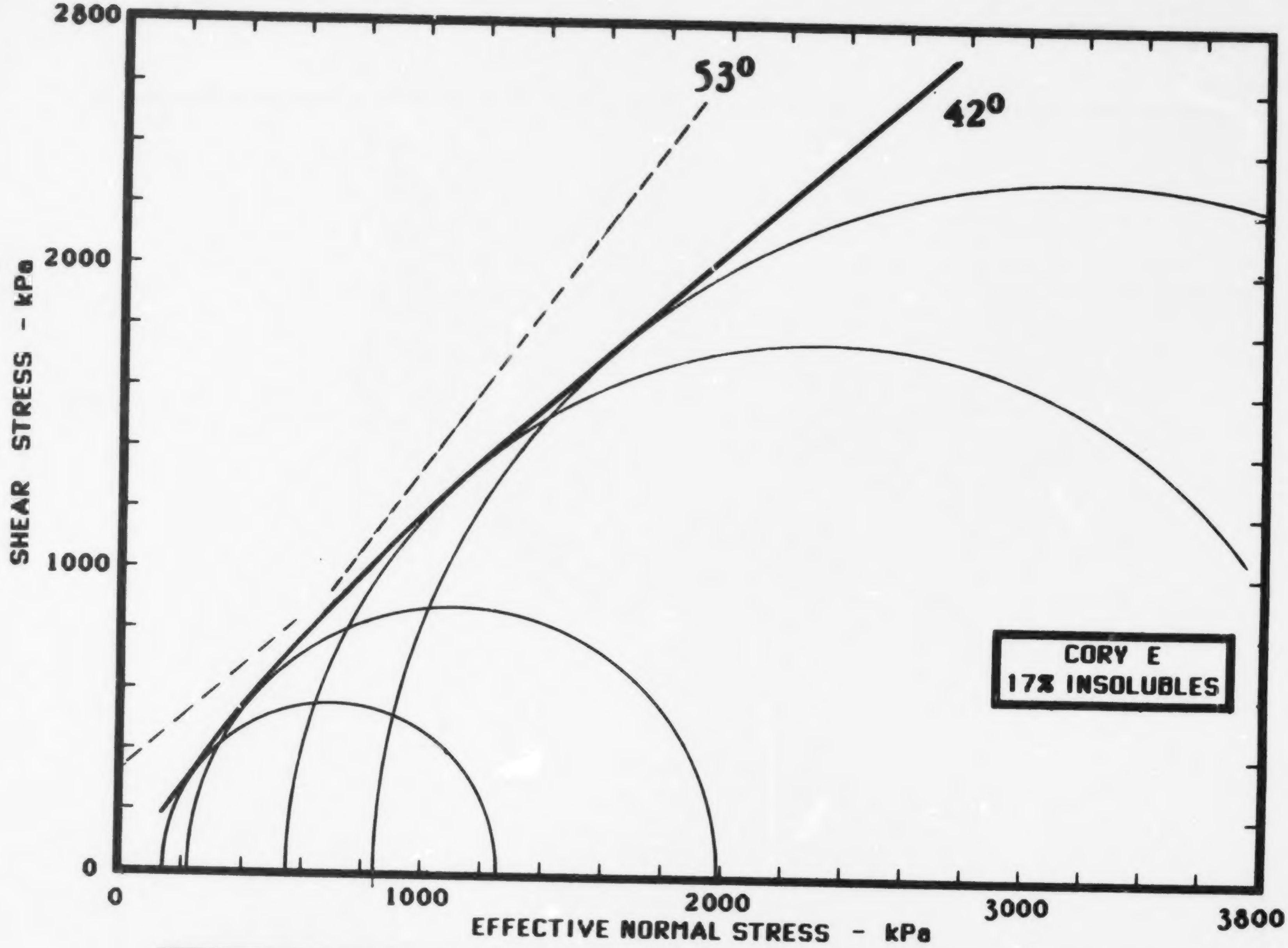
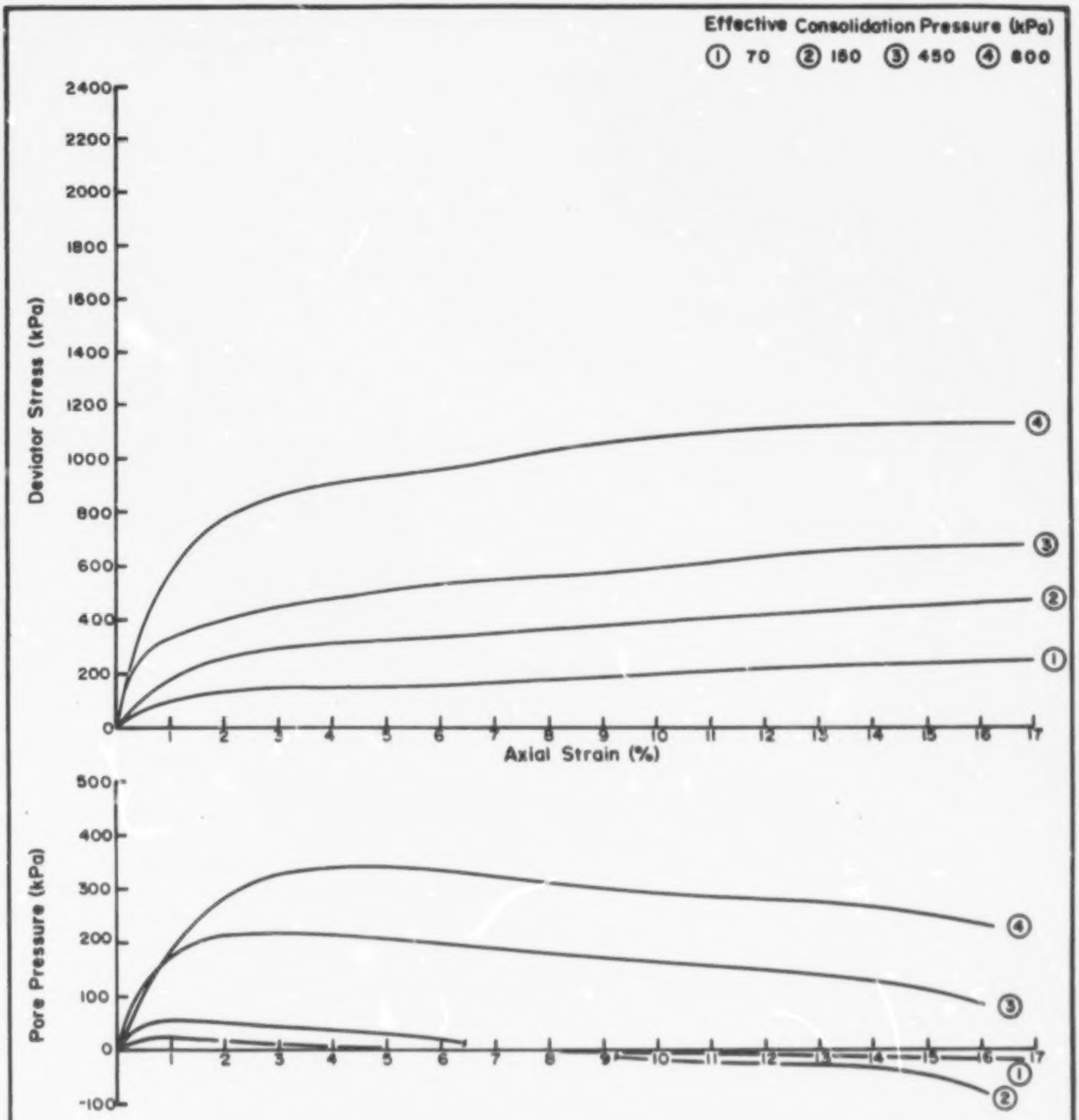


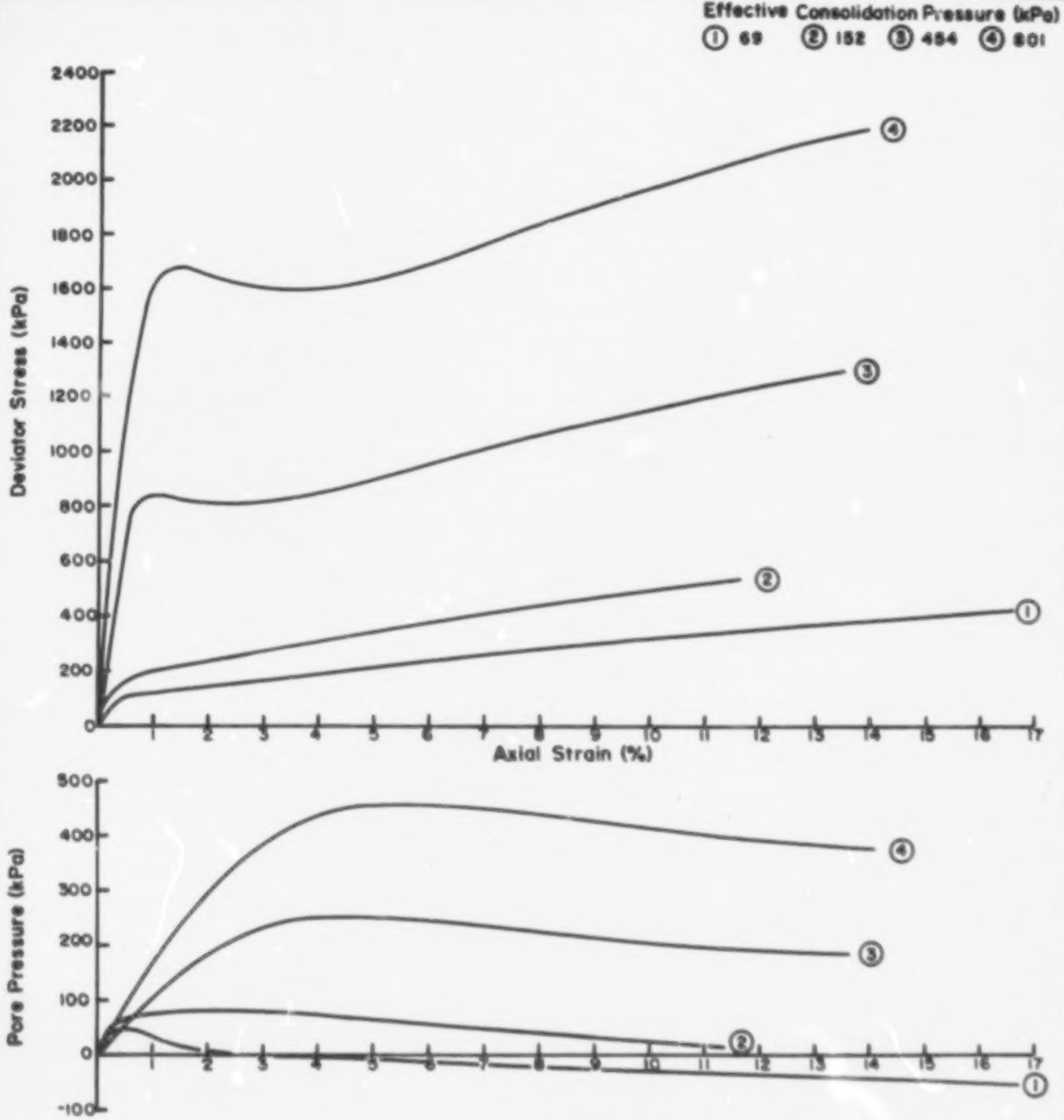
Figure A-3.10 MOHR-COULOMB FAILURE ENVELOPE FOR CU TRIAXIAL TEST - CORY E

STRESS-STRAIN PLOTS

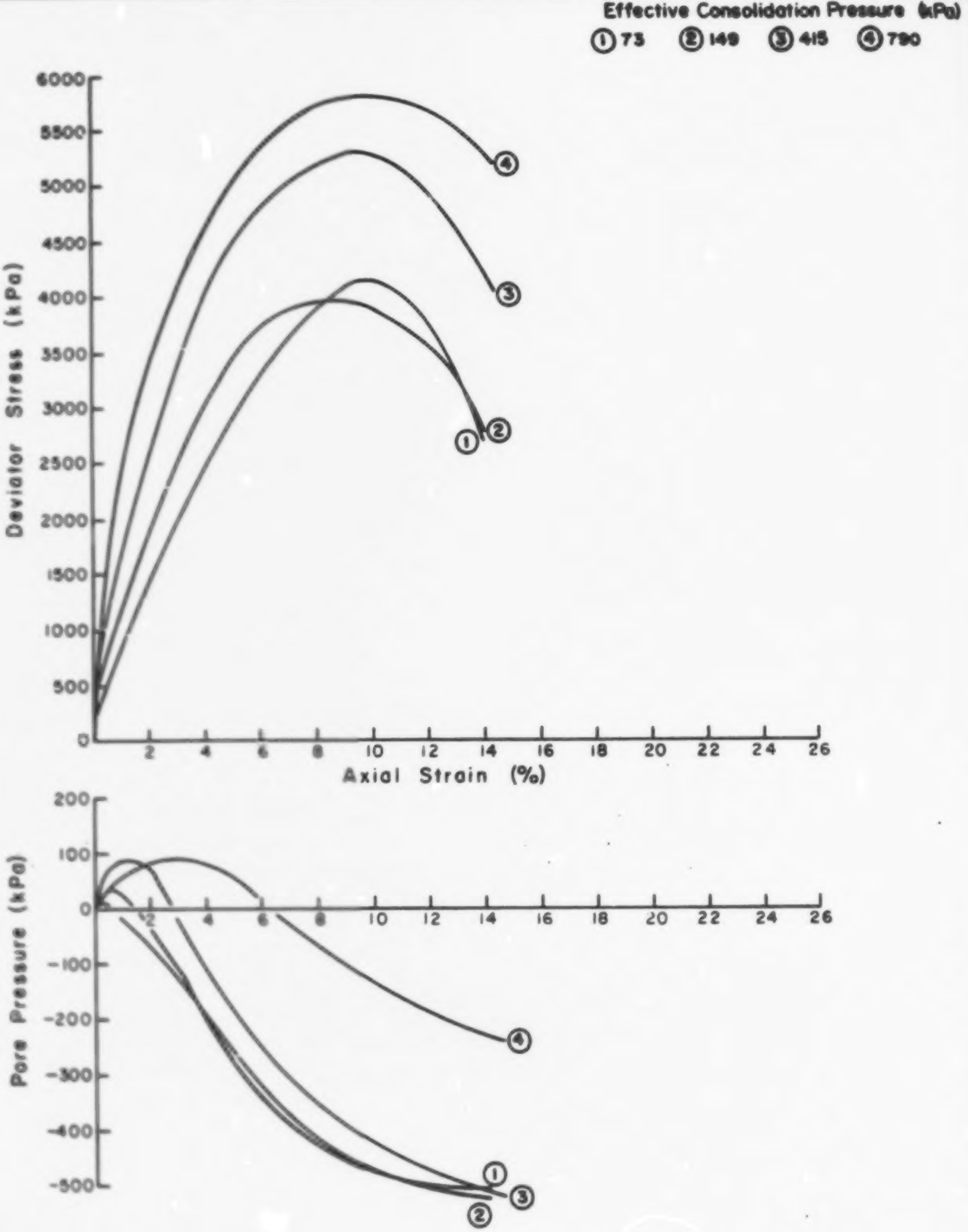
Triaxial Test



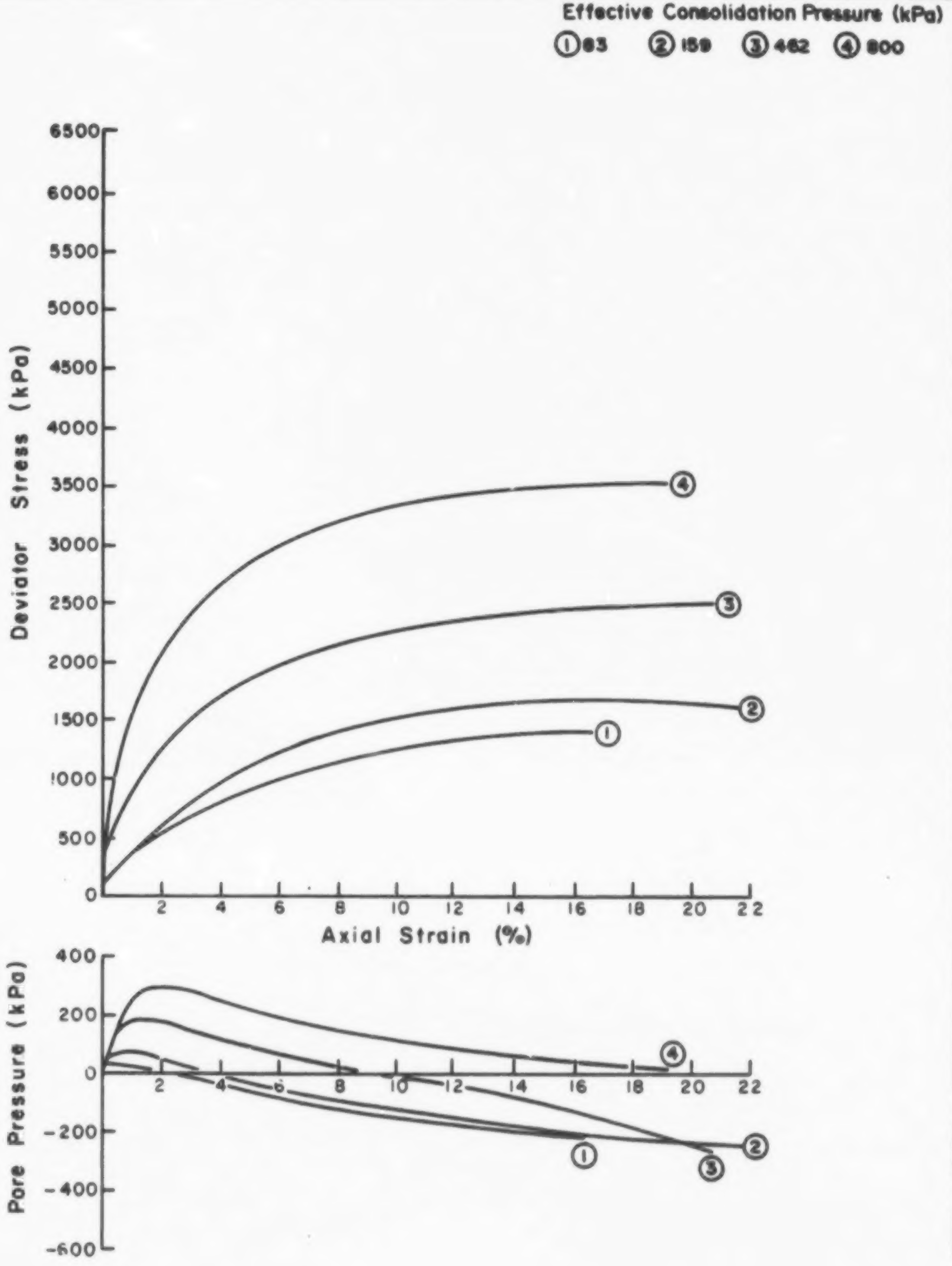
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test Consolidated Undrained Roc. A Insolubles	ACC'T No.
DESIGNED BY:				PROJECT No
DRAWN BY: LS	AUG. 1984	Potash Corporation of Saskatchewan		DWG. No 3 1
CHECKED BY:				
APPROVED BY:				SH. of REV.



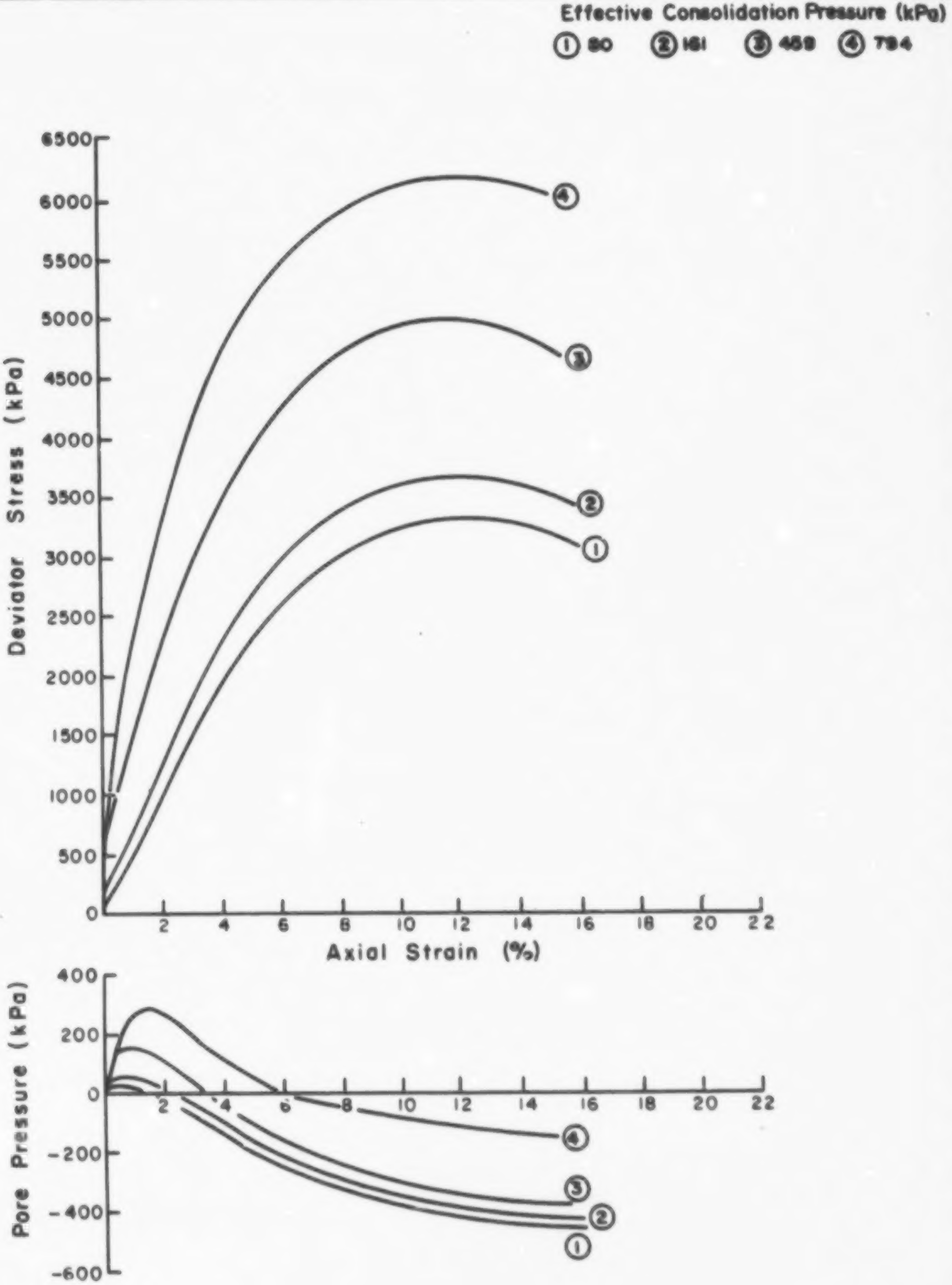
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test	ACC'T No.
DESIGNED BY:			Consolidated Undrained	PROJECT No
DRAWN BY: LS	AUG. 1984	Potash Corporation of Saskatchewan	Roc. B – Slimes	DWG. No 3 2
CHECKED BY:			10 % Insolubles	
APPROVED BY:				SH. of REV.



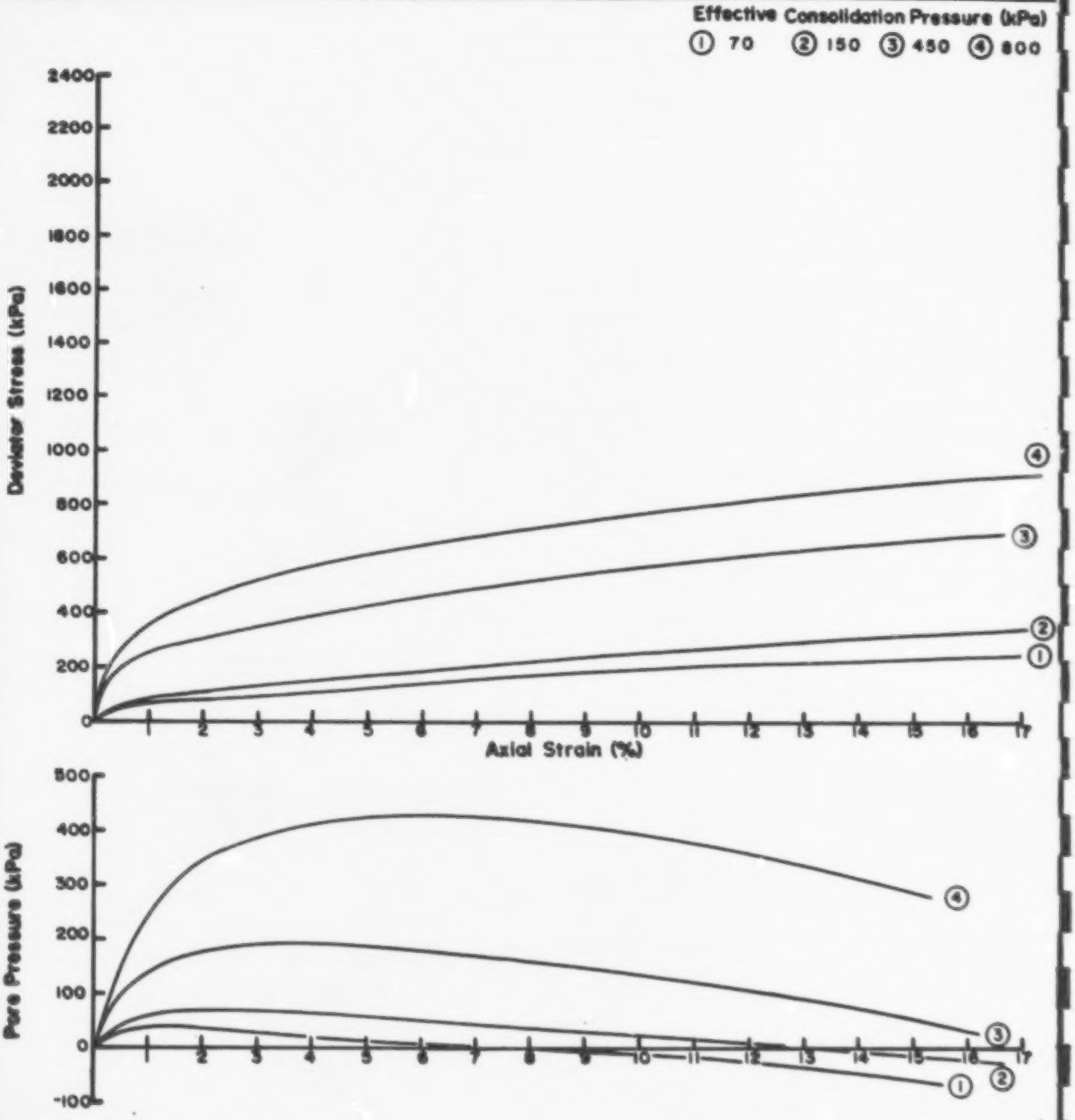
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Consolidated Undrained	PROJECT No
DRAWN BY:	SEPT, 1984		Roc. C	DWG. No 3 3
CHECKED BY:			Salt Tails	SH. of REV.
APPROVED BY:				



SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville	Triaxial Test Consolidated Undrained Roc. D-Salt 32% Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No
DRAWN BY: P.R.	SEPT, 1984			DWG. No 3 4
CHECKED BY:				
APPROVED BY:				SH. of REV.



SECTION:		LOCATION: Rocanville	TITLE: Triaxial Test Consolidated Undrained Roc. E- Salt 19% Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: P.R.	SEPT, 1984			DWG. No 3 5
CHECKED BY:				SH. of REV.
APPROVED BY:				



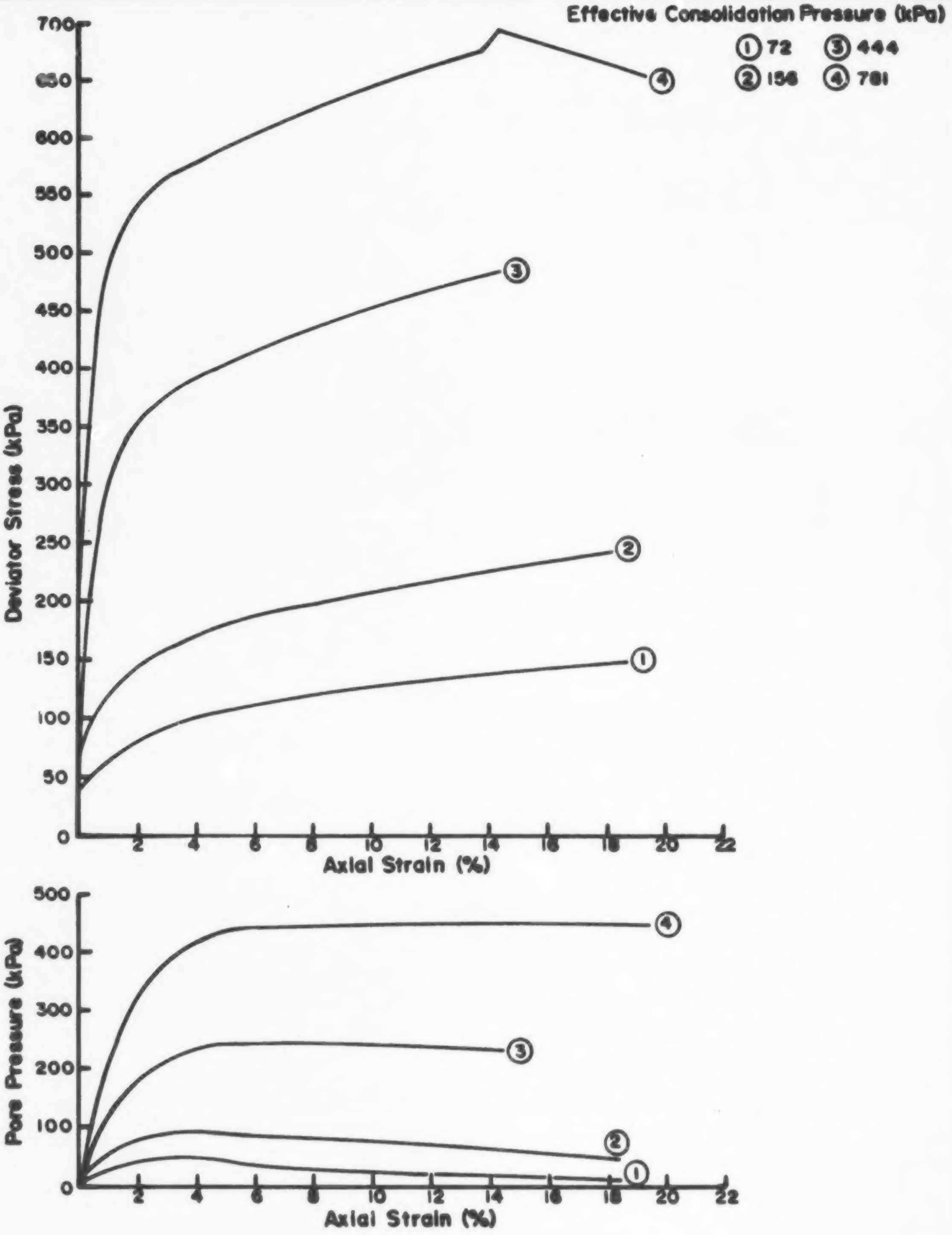
SECTION:
SCALE:
DATE
DESIGNED BY:
DRAWN BY: LS AUG. 1984
CHECKED BY:
APPROVED BY:

LOCATION:
Cory

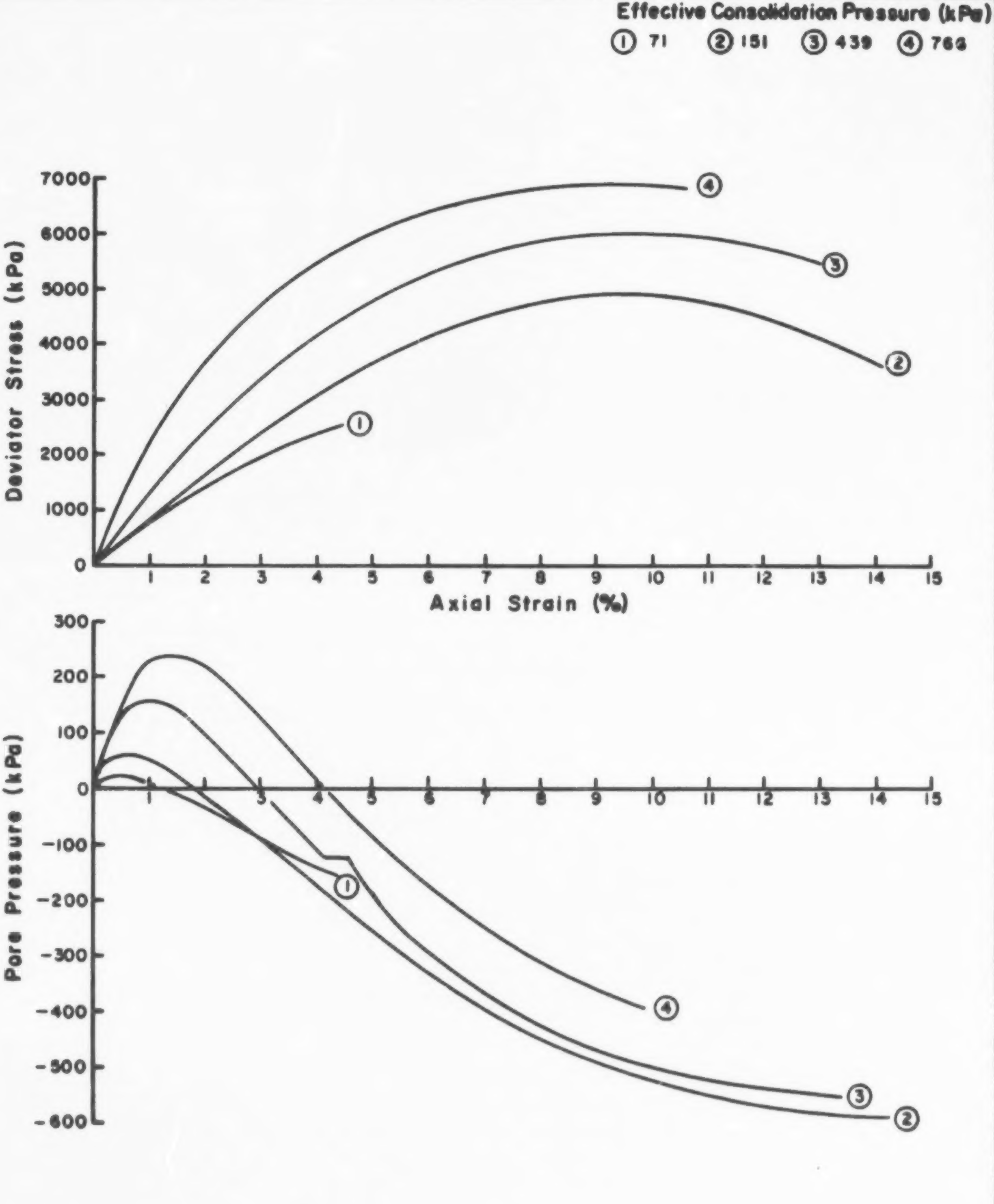
Potash Corporation of Saskatchewan

TITLE:
Triaxial Test
Consolidated Undrained
Cory A
Insolubles

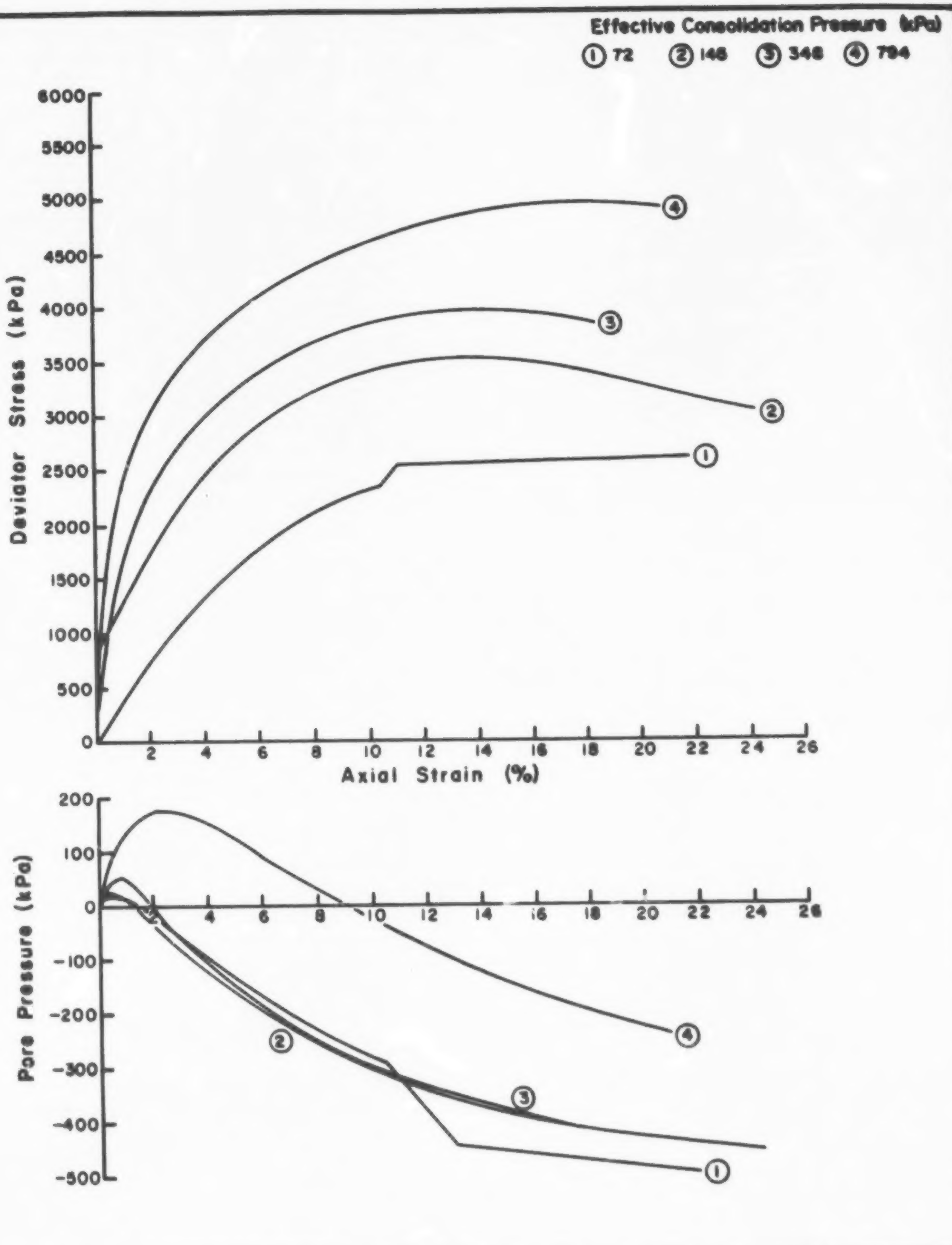
M.C.C. No.
ACC'T No.
PROJECT No.
DWG. No. 3 6
SH. of REV.



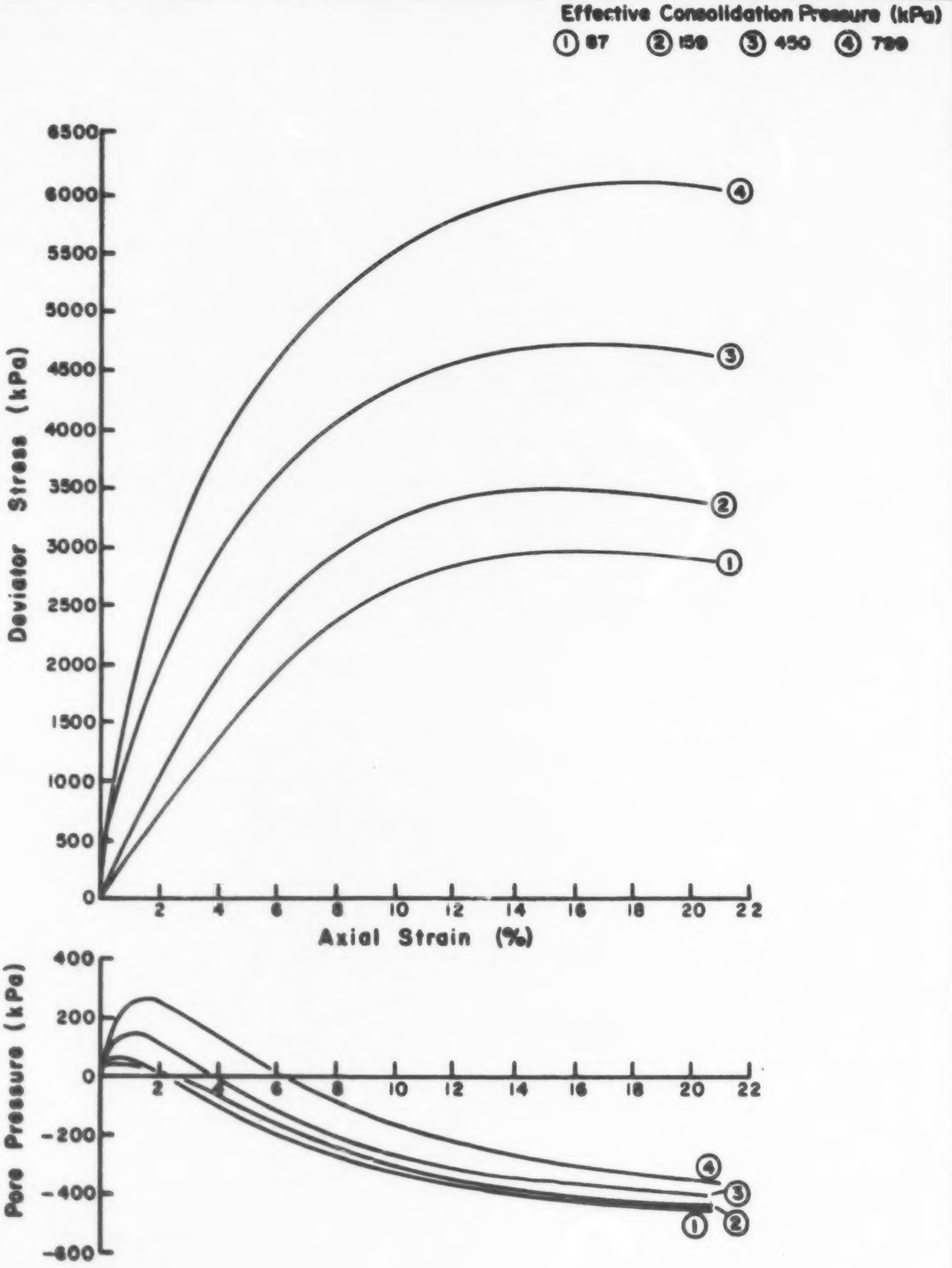
SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Cory	Triaxial Test Consolidated Undrained Cory B-Slimes 33% Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: L.A.	AUG. 1984			DWG. No. 3 7
CHECKED BY:				
APPROVED BY:				SH. of REV.



SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test Consolidated Undrained Cory C Salt Tails	ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY: LS	SEPT, 1984	Potash Corporation of Saskatchewan		DWG. No. 3 8
CHECKED BY:				
APPROVED BY:				SH. of REV.



SECTION:		**LOCATION:** Cory	**TITLE:**	**M.C.C. No.**
SCALE:	**DATE**		Triaxial Test	**ACC'T No.**
DESIGNED BY:		Potash Corporation of Saskatchewan	Consolidated Undrained	**PROJECT No.**
DRAWN BY: P.R.	SEPT, 1984		Cory D-Salt	**DWG. No.** 3 9
CHECKED BY:			10% Insolubles	**SH.** of **REV.**
APPROVED BY:				



SECTION:
SCALE:
DATE
DESIGNED BY:
DRAWN BY:
SEPT, 1984
CHECKED BY:
APPROVED BY:

LOCATION:
Cory

Potash Corporation of Saskatchewan

TITLE:
Triaxial Test
Consolidated Undrained
Cory E-Salt
17% Insolubles

M.C.C. No.
ACC'T No.
PROJECT No.
DWG. No. 3 10
SH. of
REV.

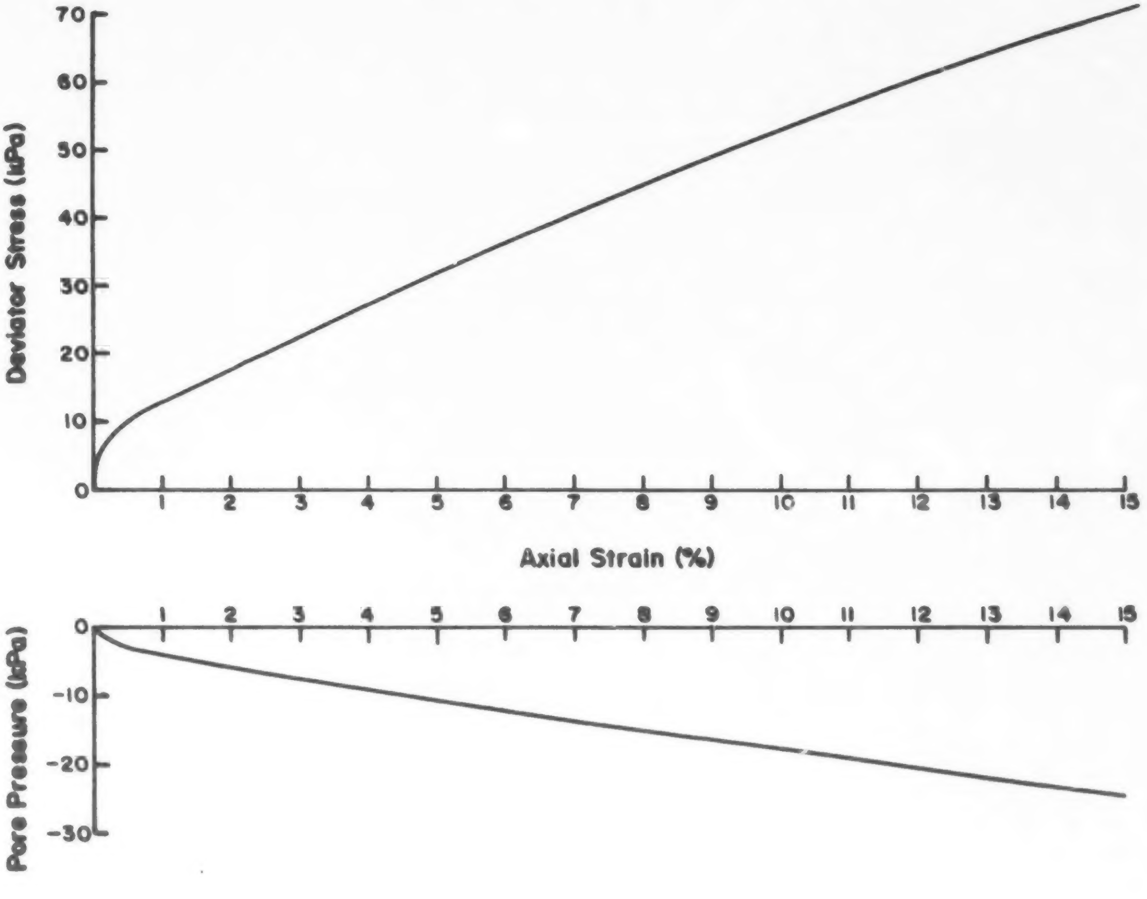
APPENDIX A
SECTION 4

UNCONSOLIDATED-UNDRAINED TRIAXIAL AND UNCONFINED COMPRESSION TEST DATA

STRESS-STRAIN PLOTS

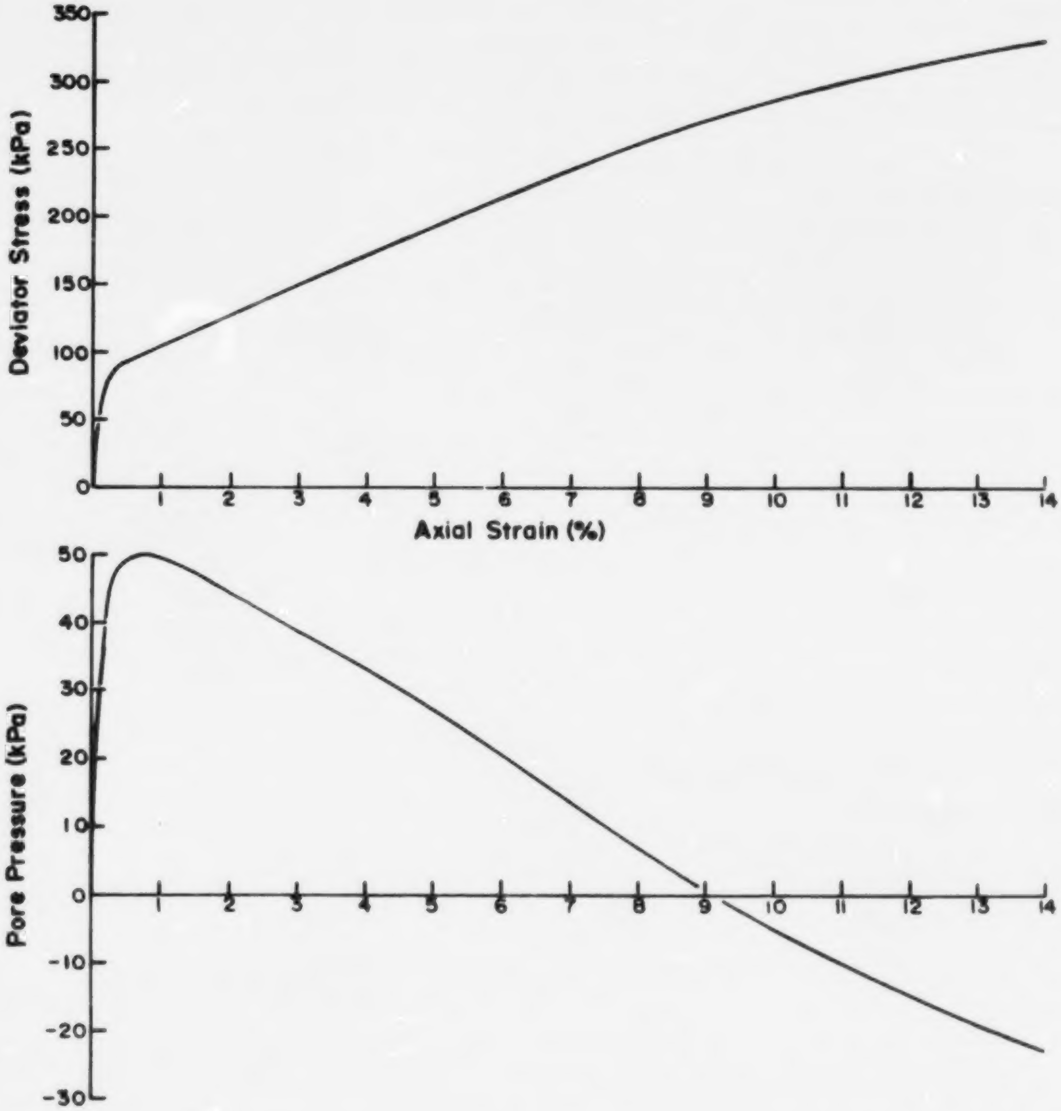
Unconsolidated-Undrained Triaxial Tests

Effective Consolidation Pressure = 0 kPa



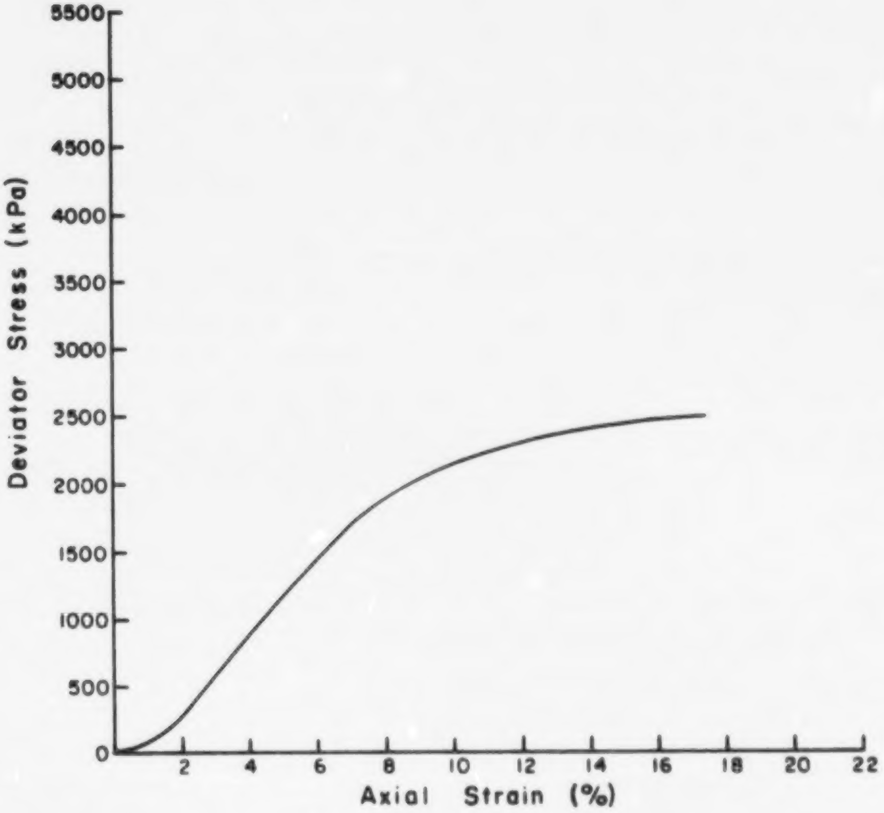
SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville	Triaxial Test Unconsolidated Undrained Roc. A Insolubles	ACC'T No.
DESIGNED BY:				PROJECT No.
DRAWN BY: P.R.	SEPT.1984	Potash Corporation of Saskatchewan		DWG. No. 4 1
CHECKED BY:				
APPROVED BY:				SH. of REV.

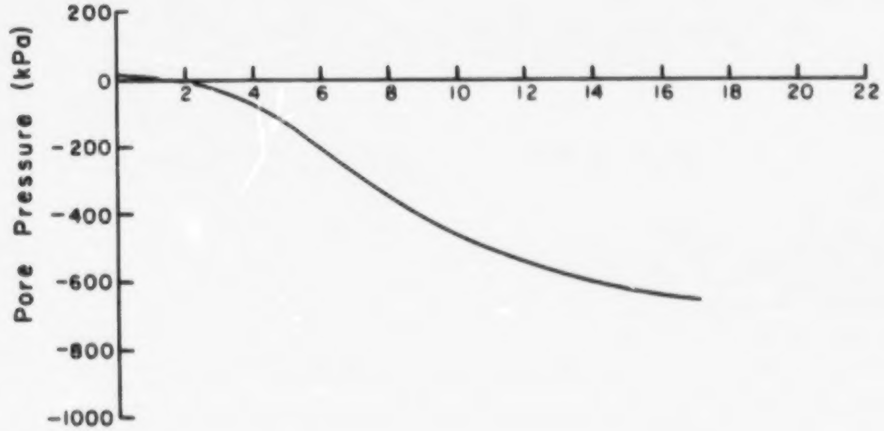
Effective Consolidation Pressure = 85 kPa



SECTION:		LOCATION:	TITLE:	M.C.C. No.
SCALE:	DATE	Rocanville	Triaxial Test	ACC'T No.
DESIGNED BY: P.R.	SEPT. 1984		Unconsolidated Undrained	PROJECT No
DRAWN BY:		Potash Corporation of Saskatchewan	Roc. B - Slimes	DWG. No 4 2
CHECKED BY:			10% Insolubles	
APPROVED BY:				SH. of / REV.

Effective Consolidation Pressure = 28 kPa





SECTION:
SCALE:
DATE
DESIGNED BY
DRAWN BY: LG — SEPT, 1984
CHECKED BY:
APPROVED BY:

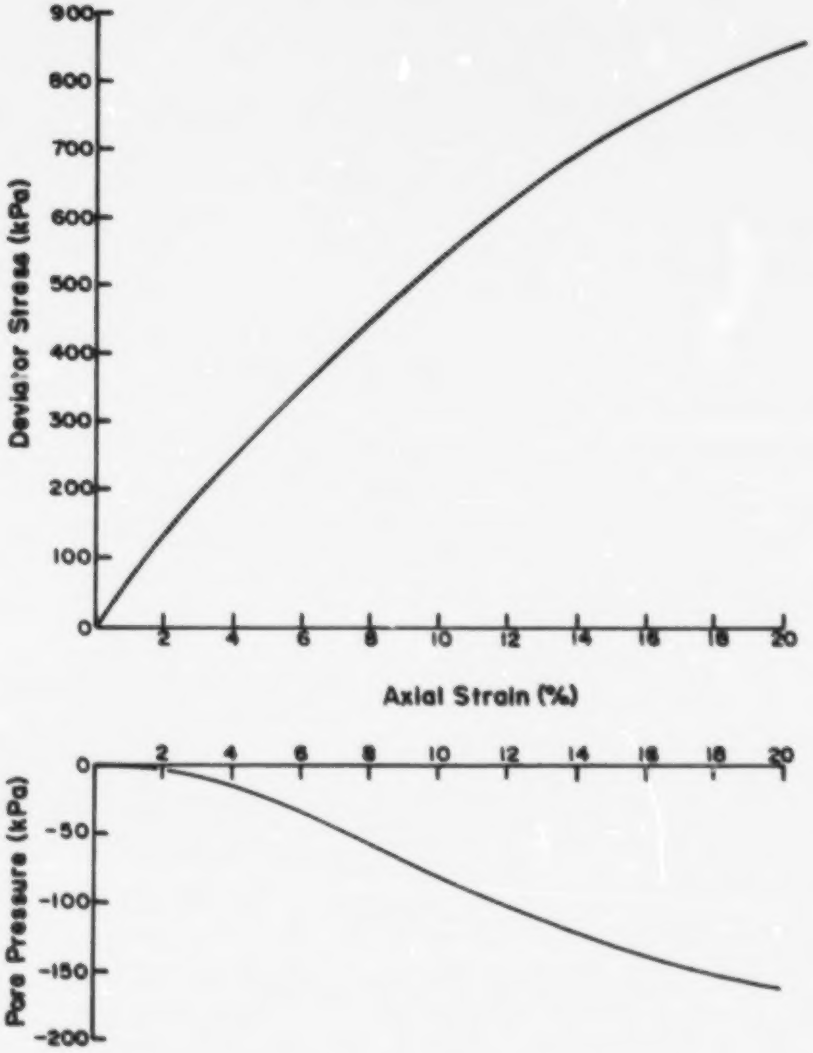
LOCATION: Rocanville

Potash Corporation of Saskatchewan

TITLE:
Triaxial Test
Unconsolidated Undrained
Roc C
Salt Tails

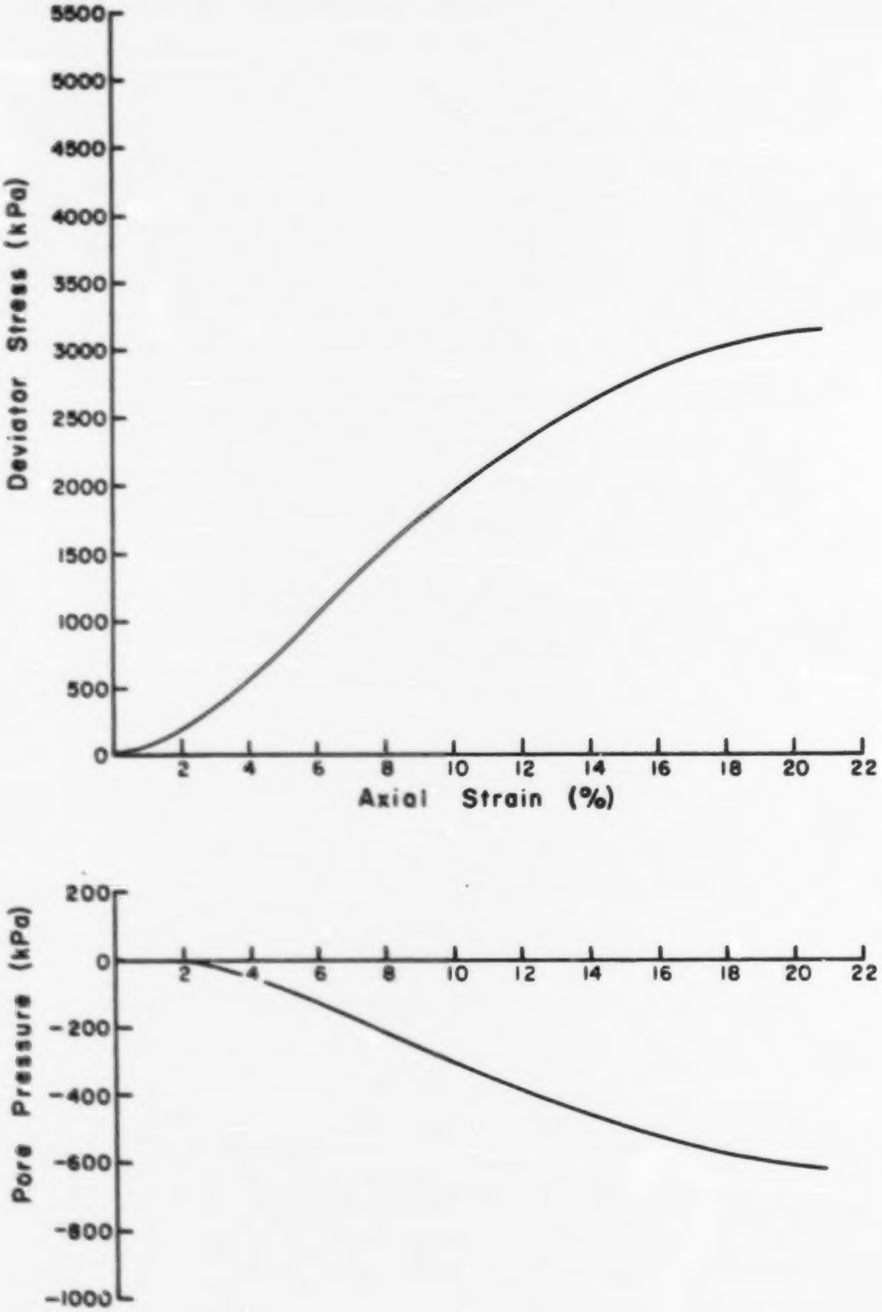
M.C.C. No.
ACC'T No.
PROJECT No.
DWG. No. 4 3
SH. of REV.

Effective Consolidation Pressure = 2 kPa



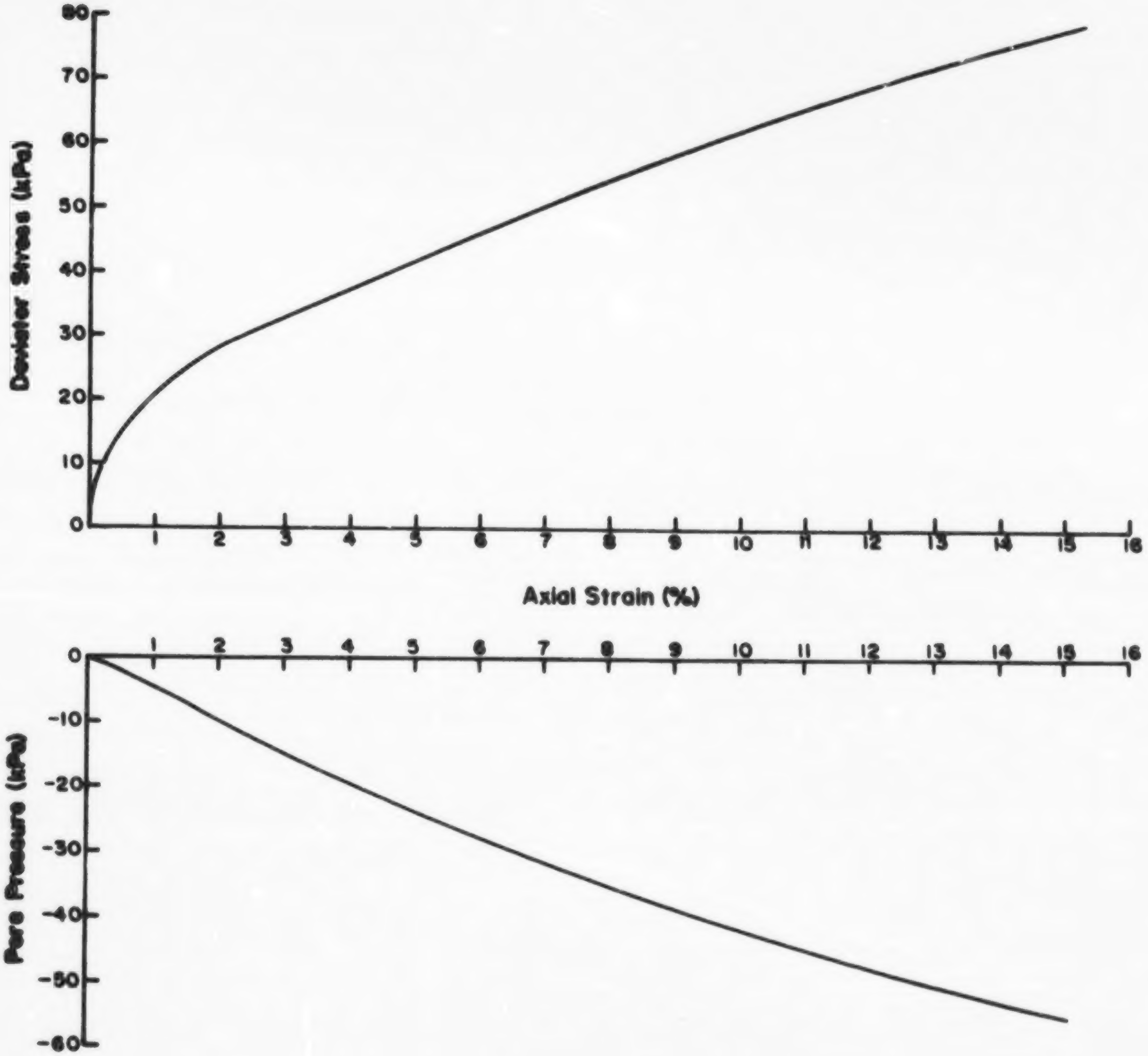
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Unconsolidated Undrained	PROJECT No.
DRAWN BY: P.R.	SEPT. 1984		Roc. D-Salt-	DWG. No. 4 4
CHECKED BY:			32% Insolubles	
APPROVED BY:				SH. of REV.

Effective Consolidation Pressure = 4 kPa



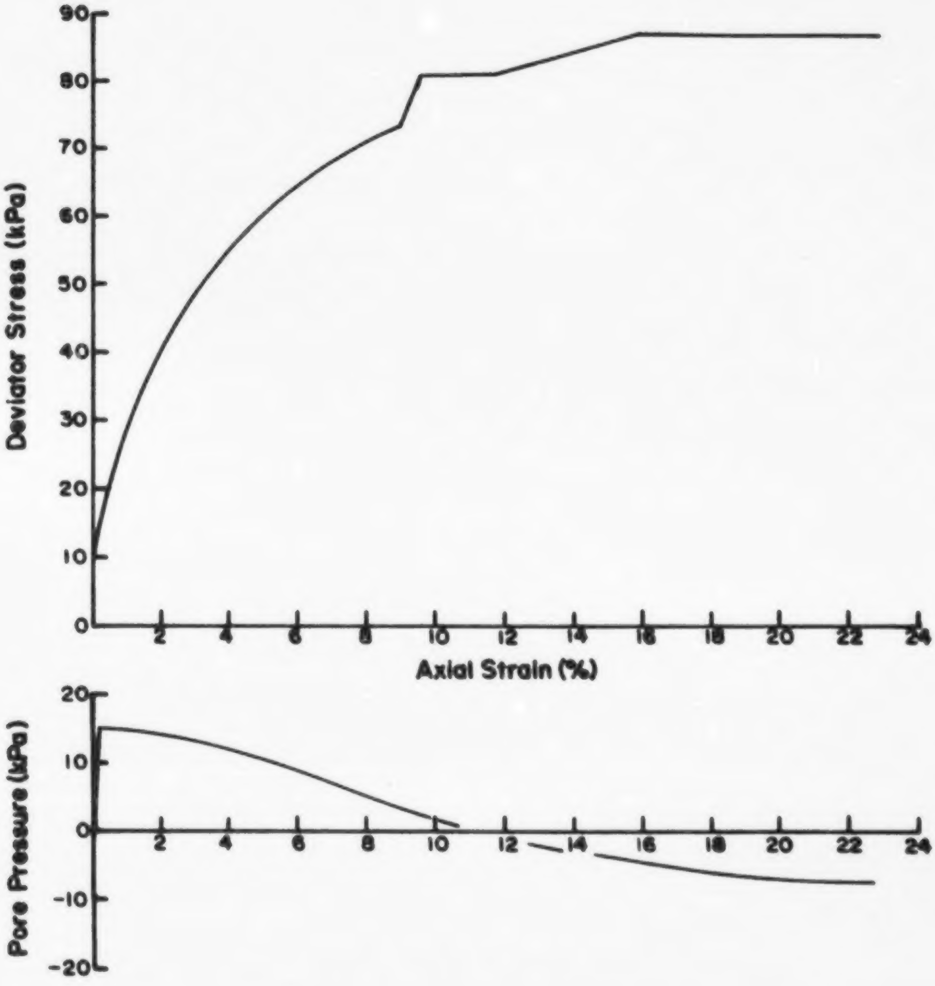
SECTION:		LOCATION: Rocanville	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan	Unconsolidated Undrained	PROJECT No
DRAWN BY: AK	SEPT, 1984		Roc E – Salt –	DWG. No. 4 5
CHECKED BY:			19% Insolubles	
APPROVED BY:				SH. of REV.

Effective Consolidation Pressure = 0 kPa



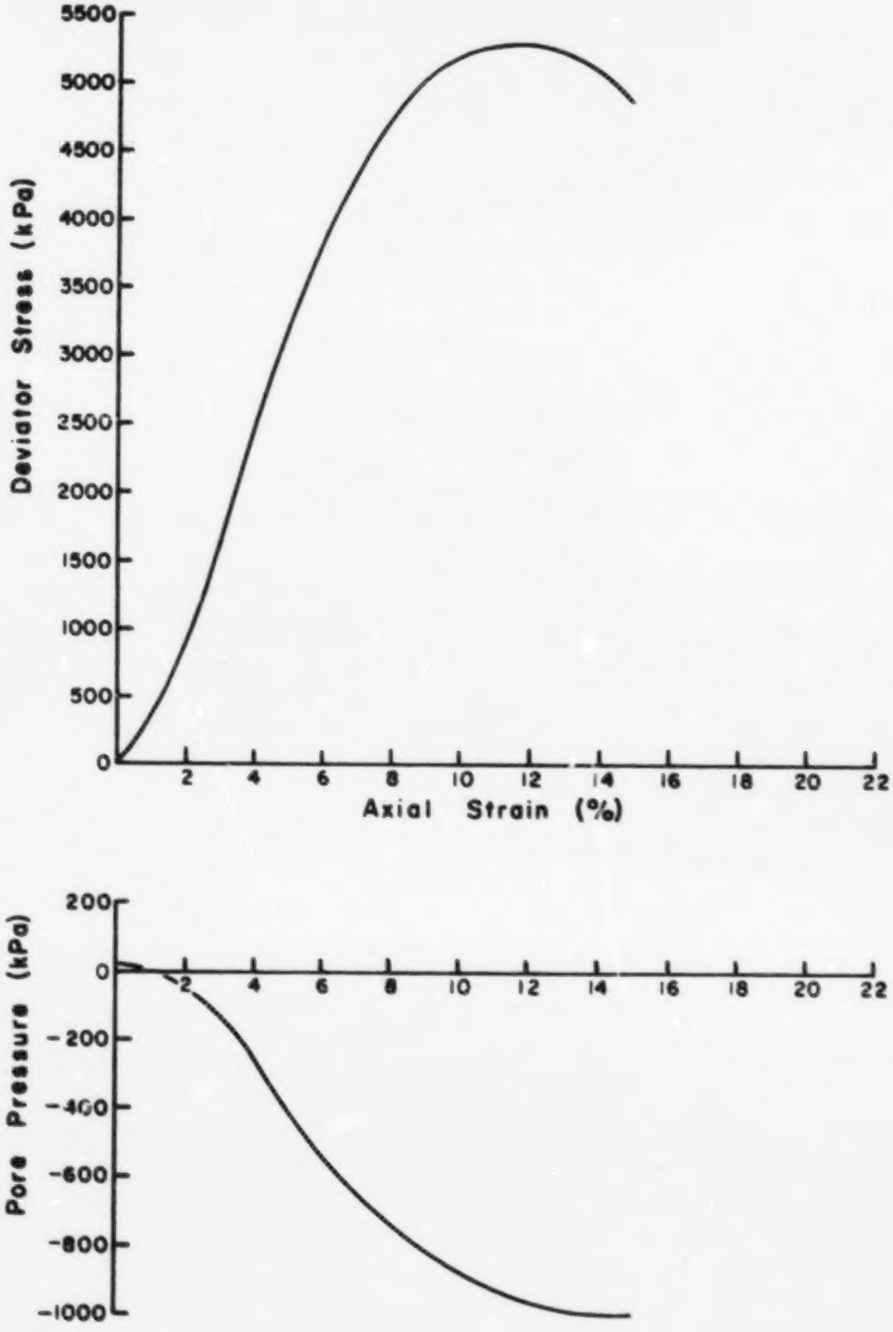
SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test Unconsolidated Undrained Cory A Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: L.A.	SEPT. 1984			DWG. No. 4 6
CHECKED BY:				
APPROVED BY:				SH. of REV.

Effective Consolidation Pressure= 35 kPa



SECTION:		**LOCATION:**	**TITLE:**	**M.C.C. No.**
SCALE:	**DATE**	Cory	Triaxial Test Unconsolidated Undrained Cory B-Slimes 33 % Insolubles	**ACC'T No.**
DESIGNED BY:				**PROJECT No.**
DRAWN BY: P.R.	SEPT. 1984	Potash Corporation of Saskatchewan		**DWG. No.** 4 7
CHECKED BY:				
APPROVED BY:				**SH. of REV.**

Effective Consolidation Pressure = 16 kPa



SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY: LS	SEPT, 1984
CHECKED BY:	
APPROVED BY:	

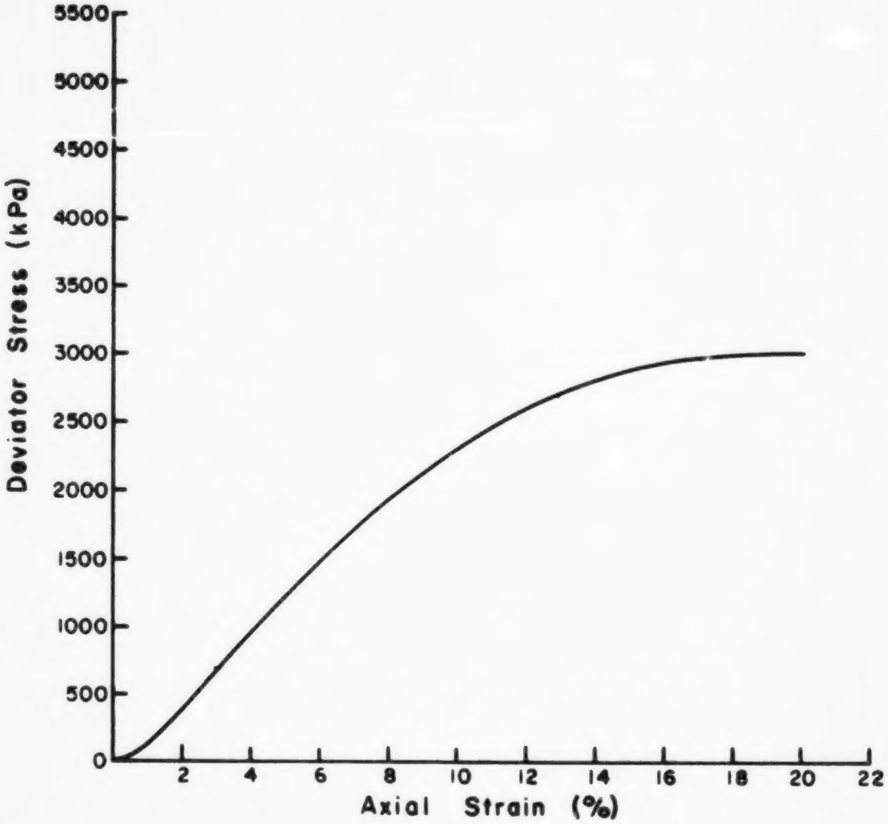
LOCATION:
Cory

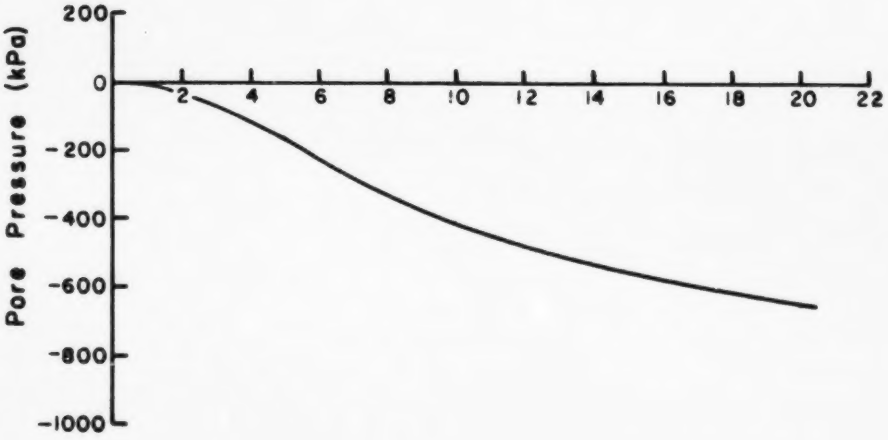
Potash Corporation of Saskatchewan

TITLE:
Triaxial Test
Unconsolidated Undrained
Cory C
Salt Tails

M.C.C. No.		
ACC'T No.		
PROJECT No.		
DWG. No. 4		8
SH.	of	REV.

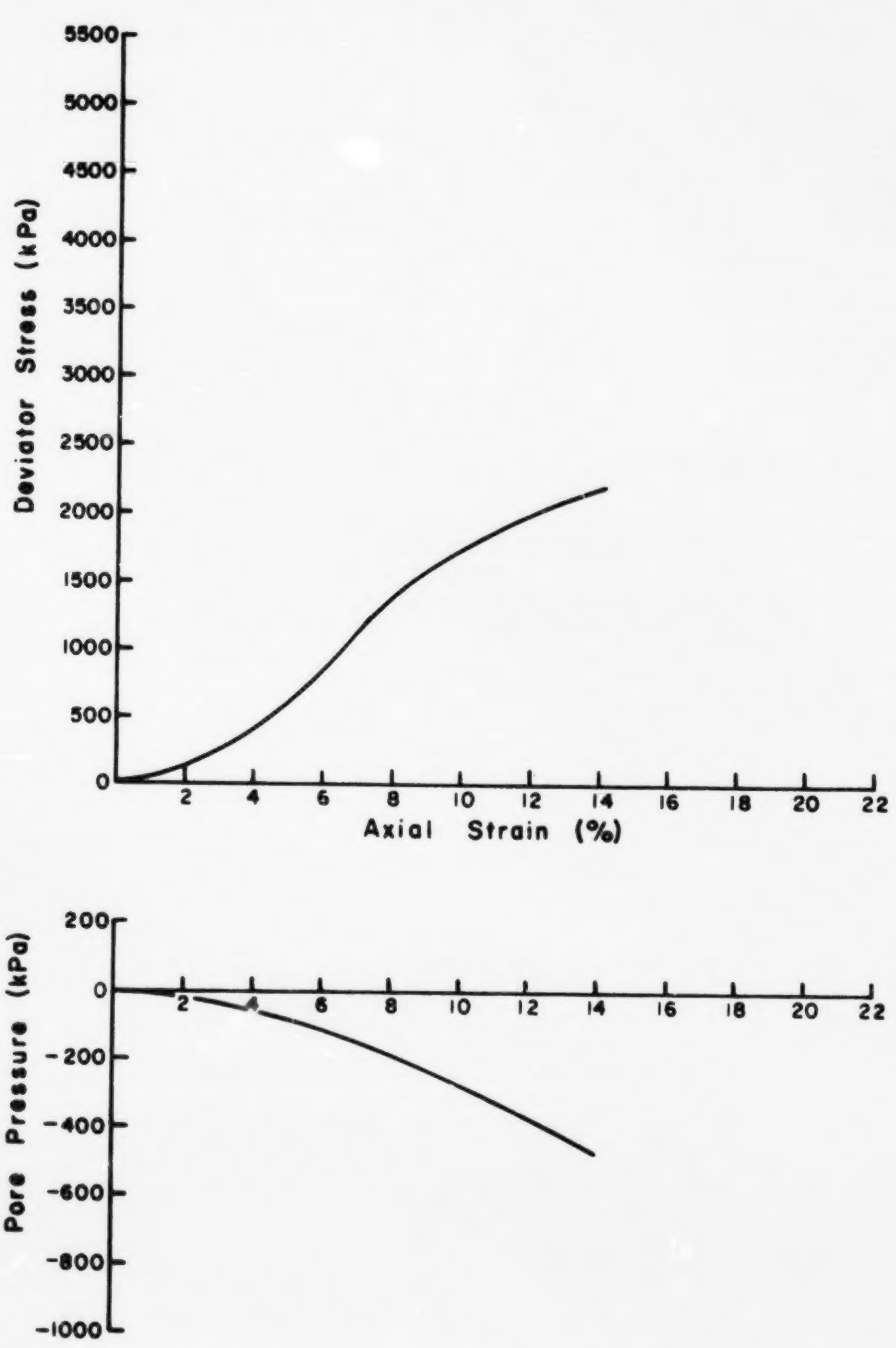
Effective Consolidation Pressure = 3 kPa





SECTION:		LOCATION: Cory	TITLE:	M.C.C. No.
SCALE:	DATE		Triaxial Test Unconsolidated Undrained Cory D - Salt - 10 % Insolubles	ACC'T No.
DESIGNED BY:		Potash Corporation of Saskatchewan		PROJECT No.
DRAWN BY: LS	SEPT, 1984			DWG. No. 4 9
CHECKED BY:				
APPROVED BY:				SH. of REV.

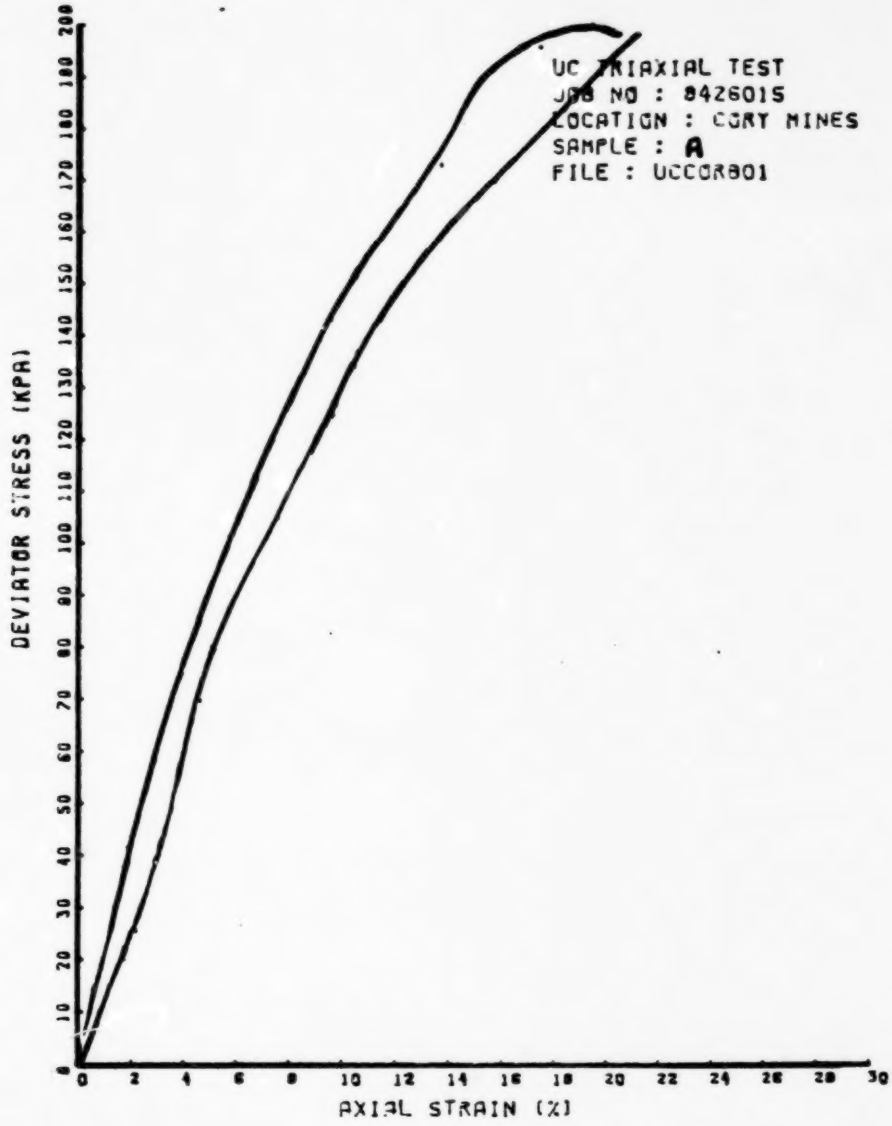
Effective Consolidation Pressure = 2 kPa



SECTION:		LOCATION: Cory	TITLE: Triaxial Test Unconsolidated Undrained Cory E - Salt - 17 % Insolubles	M.C.C. No.
SCALE:	DATE			ACC'T No.
DESIGNED BY:				PROJECT No
DRAWN BY: LS	SEPT, 1984	Potash Corporation of Saskatchewan		DWG. No 4 10
CHECKED BY:				SH. of
APPROVED BY:				REV.

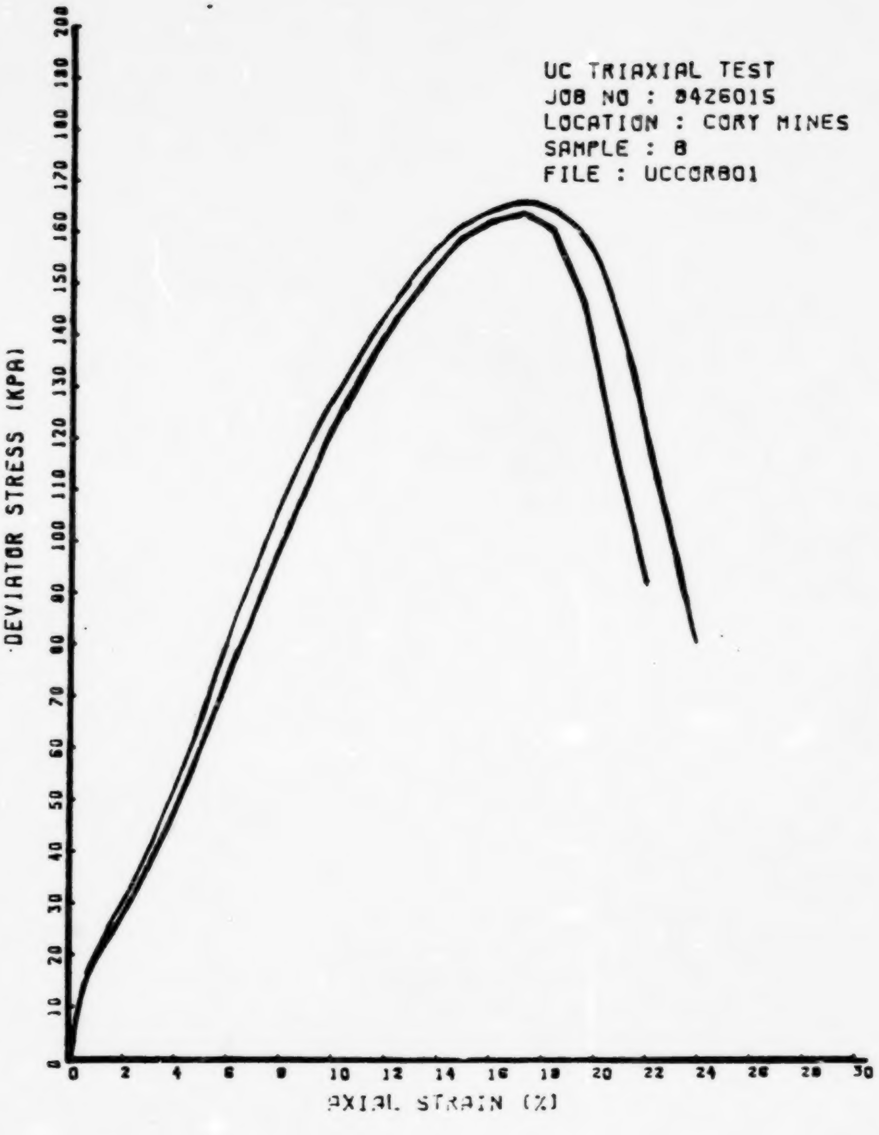
STRESS-STRAIN PLOTS

Uniaxial (Unconfined)
Compression Tests



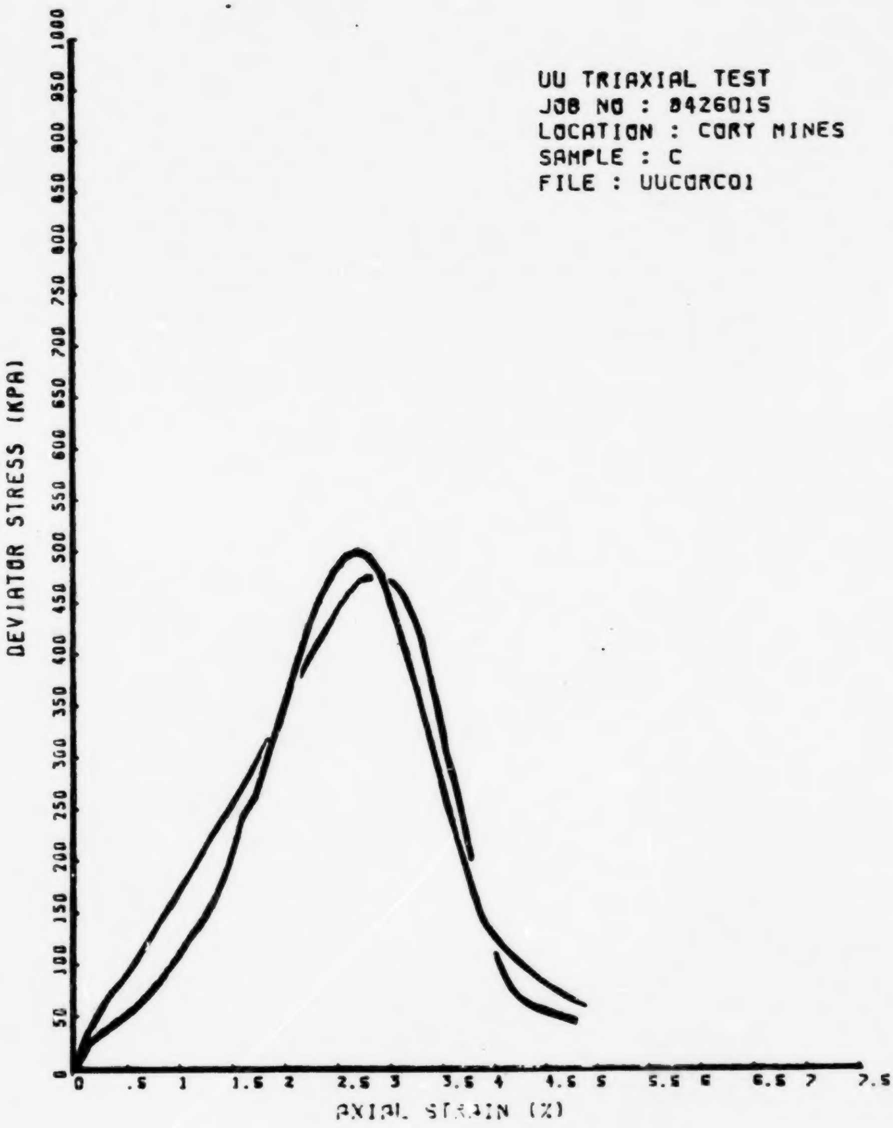
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 11



Stress - Strain Plot
UNCONFINED COMPRESSION TEST

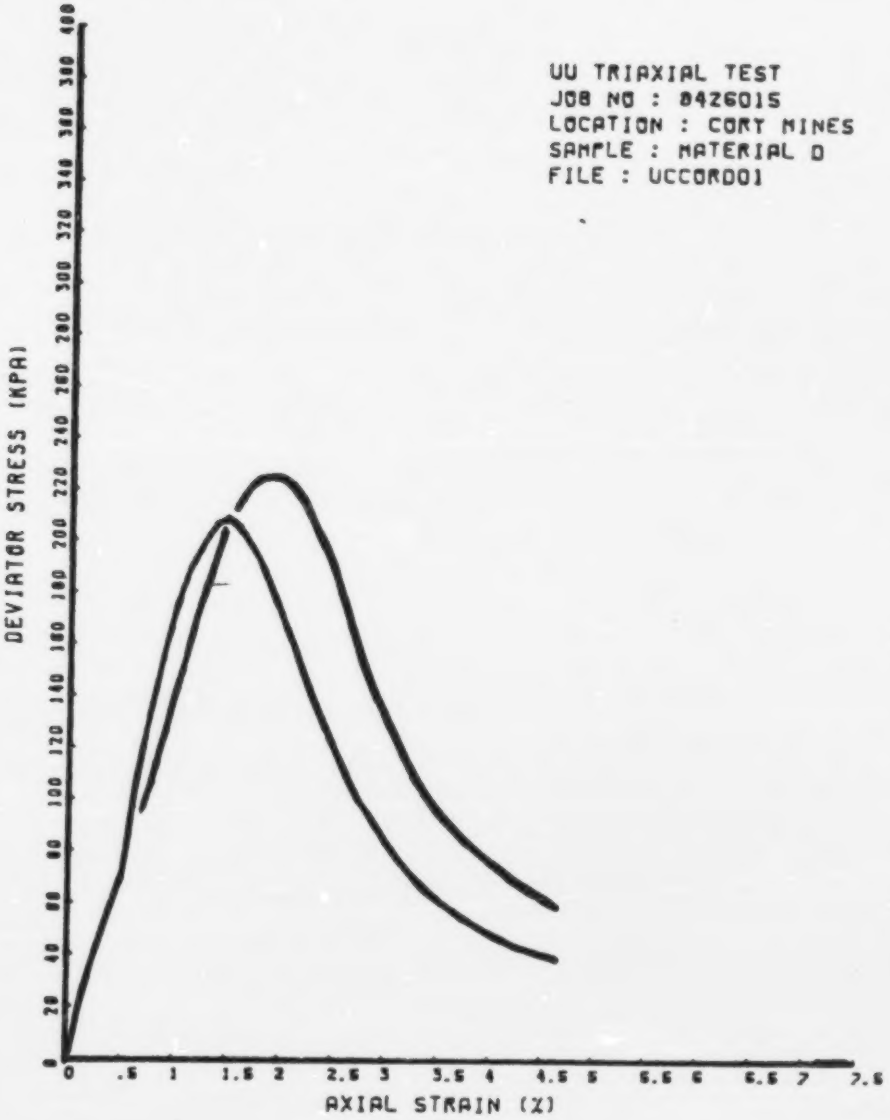
Drawing 4 12



Stress - Strain Plot

UNCONFINED COMPRESSION TEST

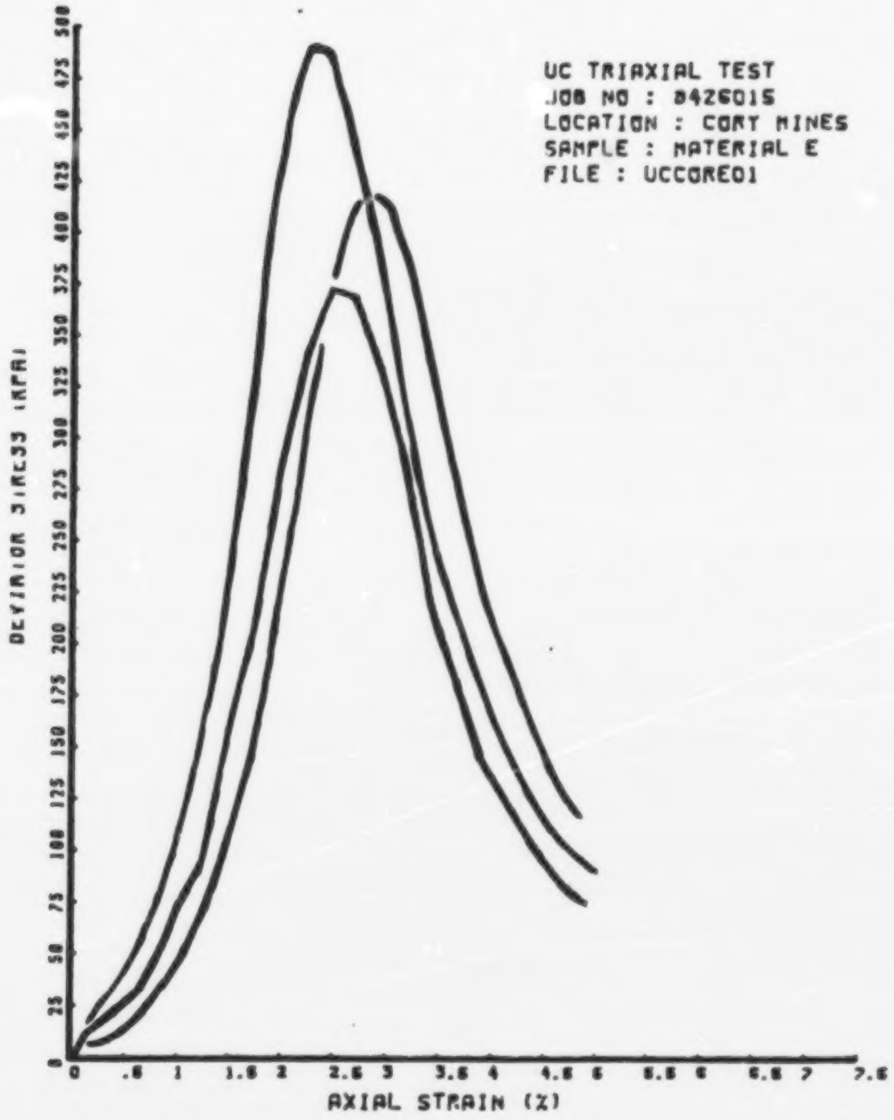
Drawing 4 13



UU TRIAXIAL TEST
JOB NO : 8426015
LOCATION : CORT MINES
SAMPLE : MATERIAL D
FILE : UCCORD01

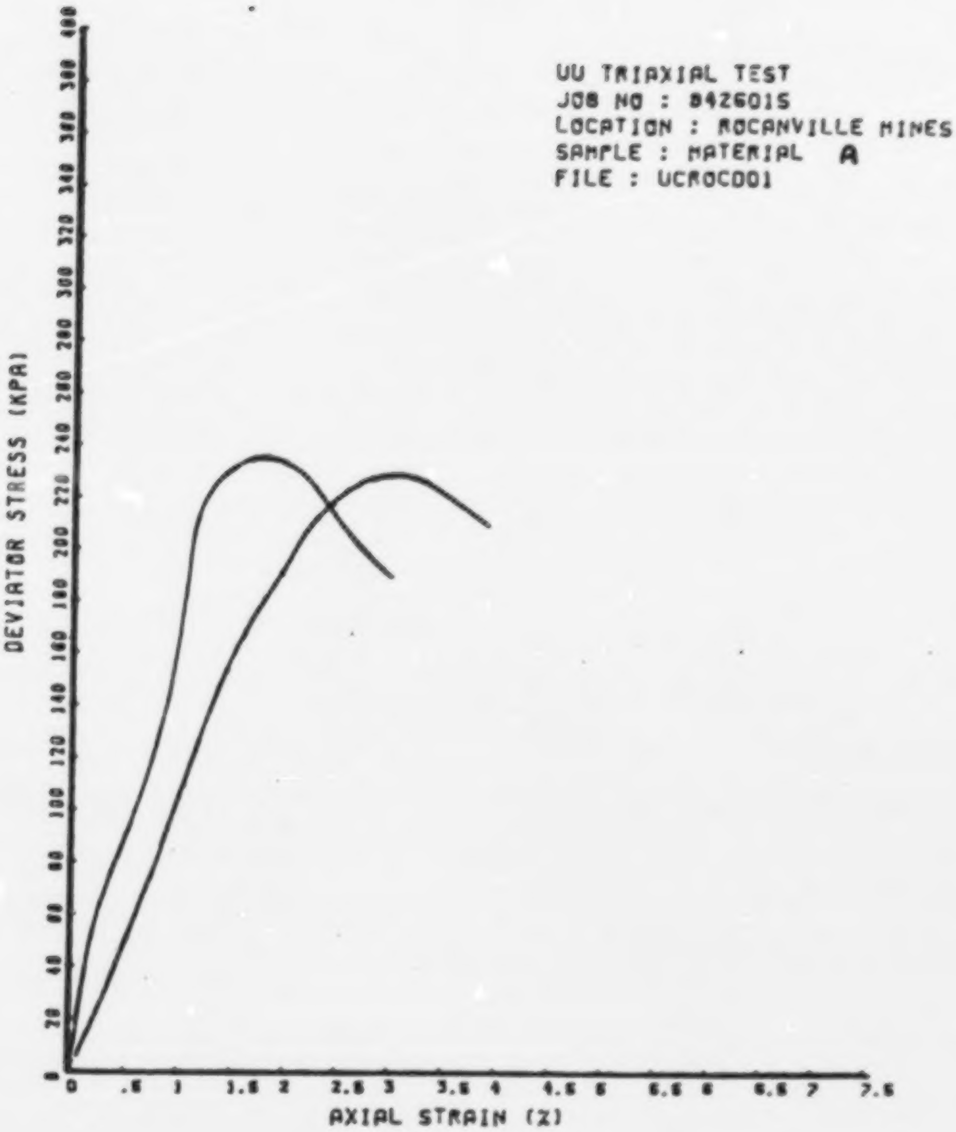
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 14



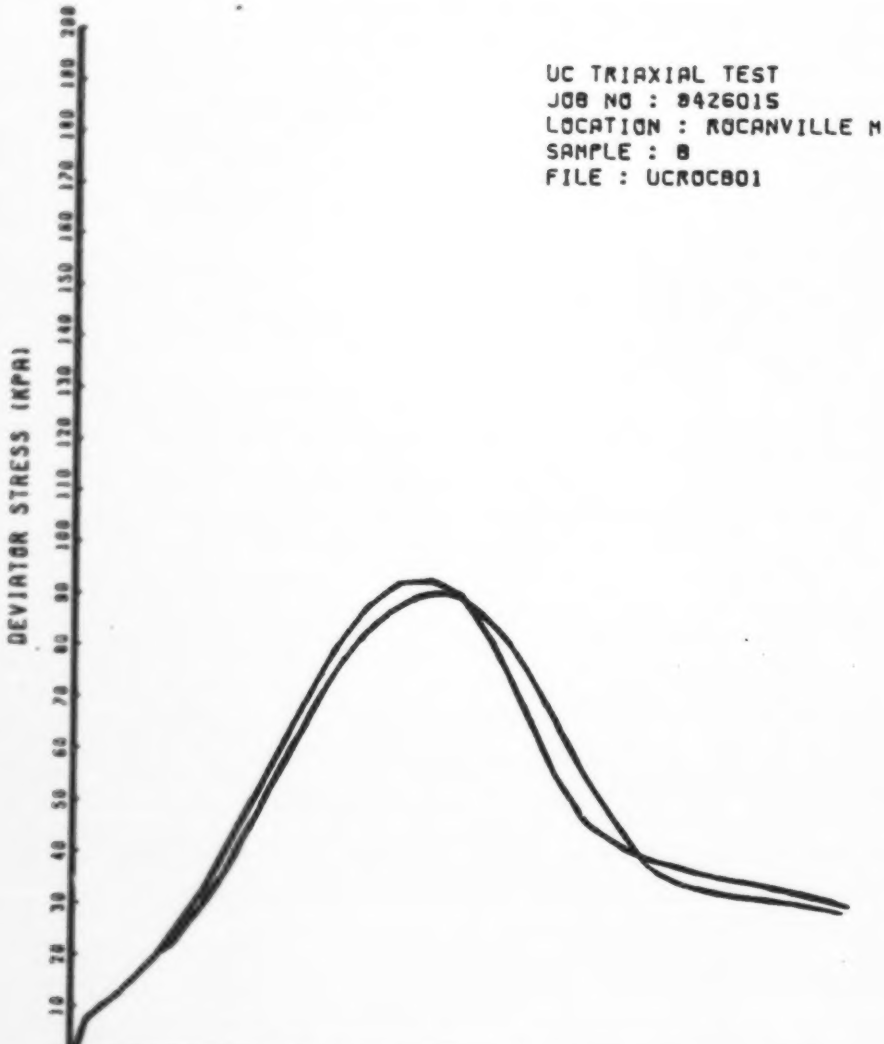
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 15



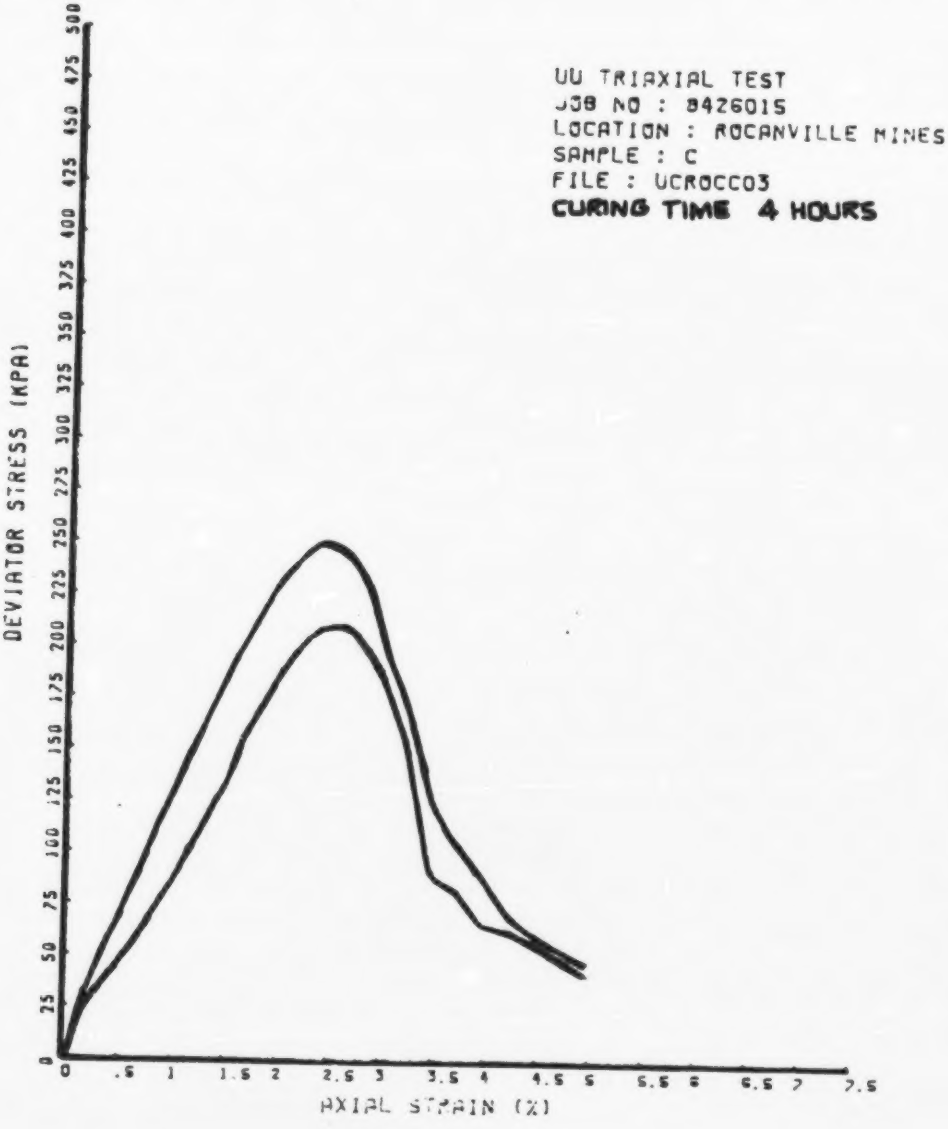
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 16



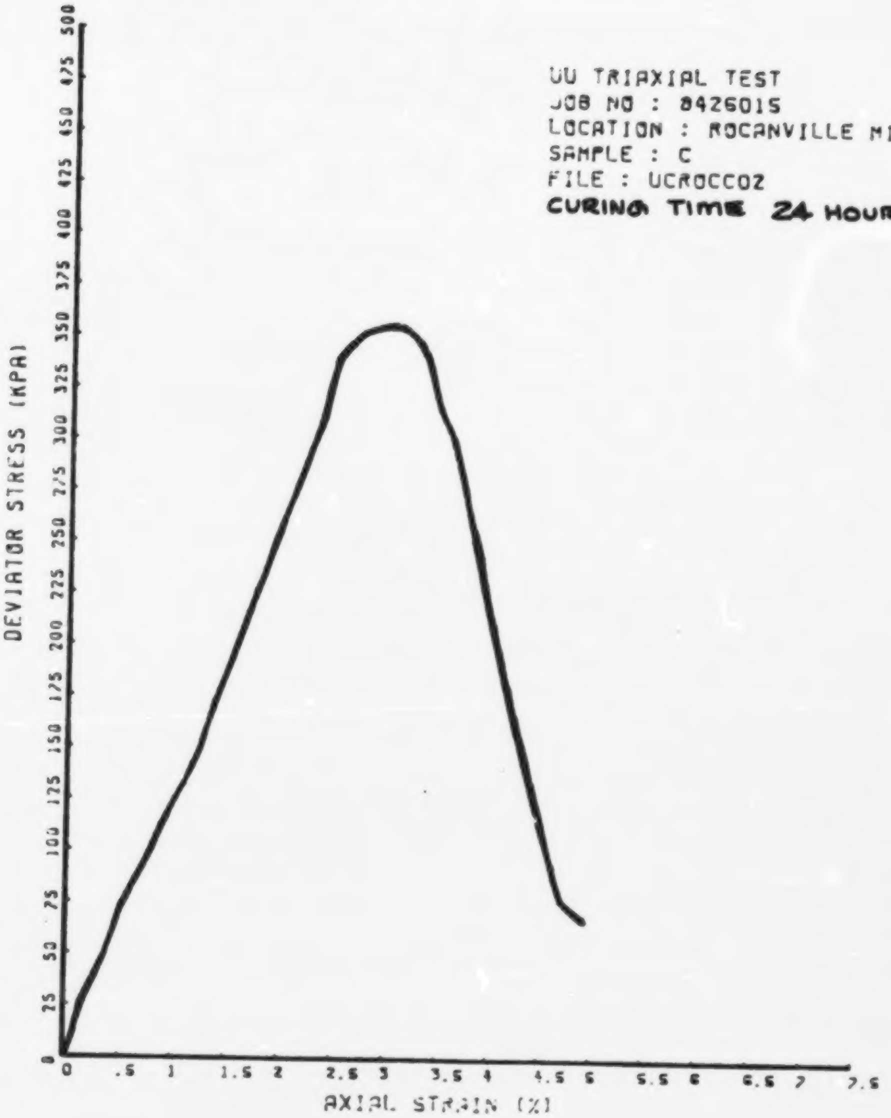
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 17



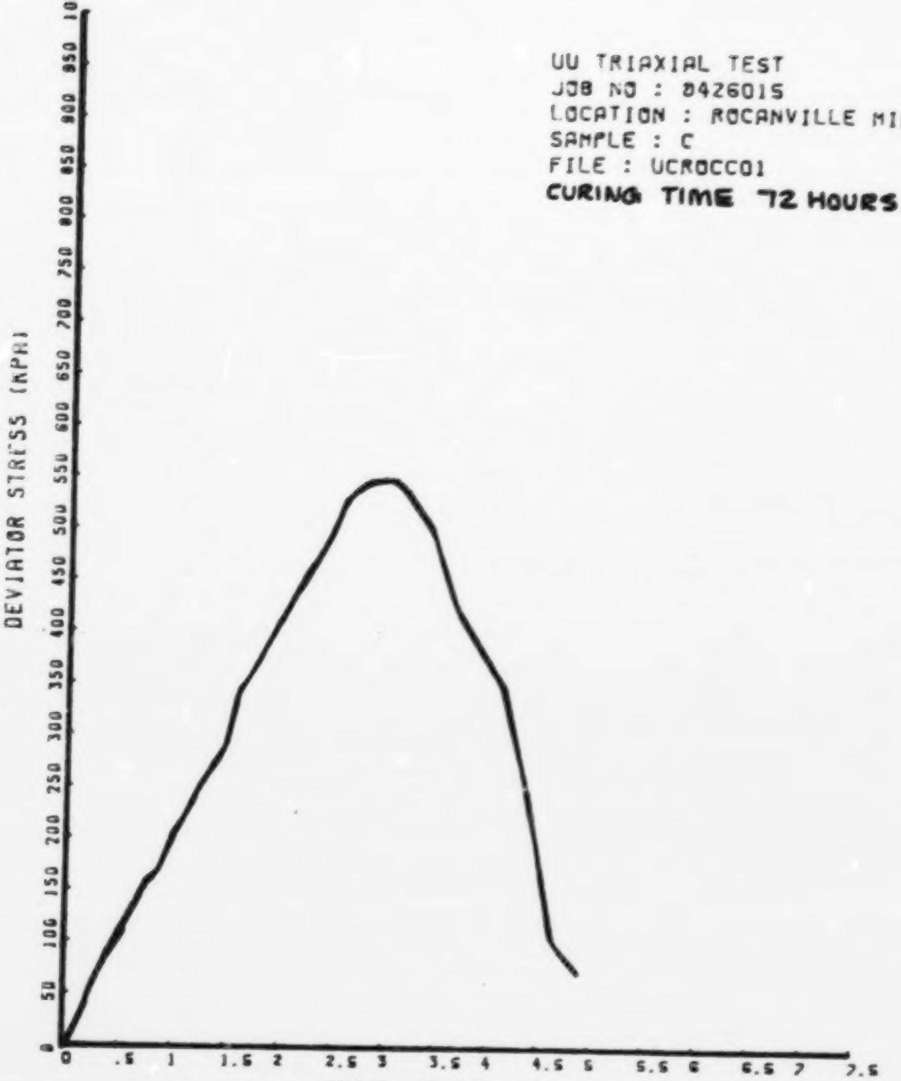
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 18



Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 19



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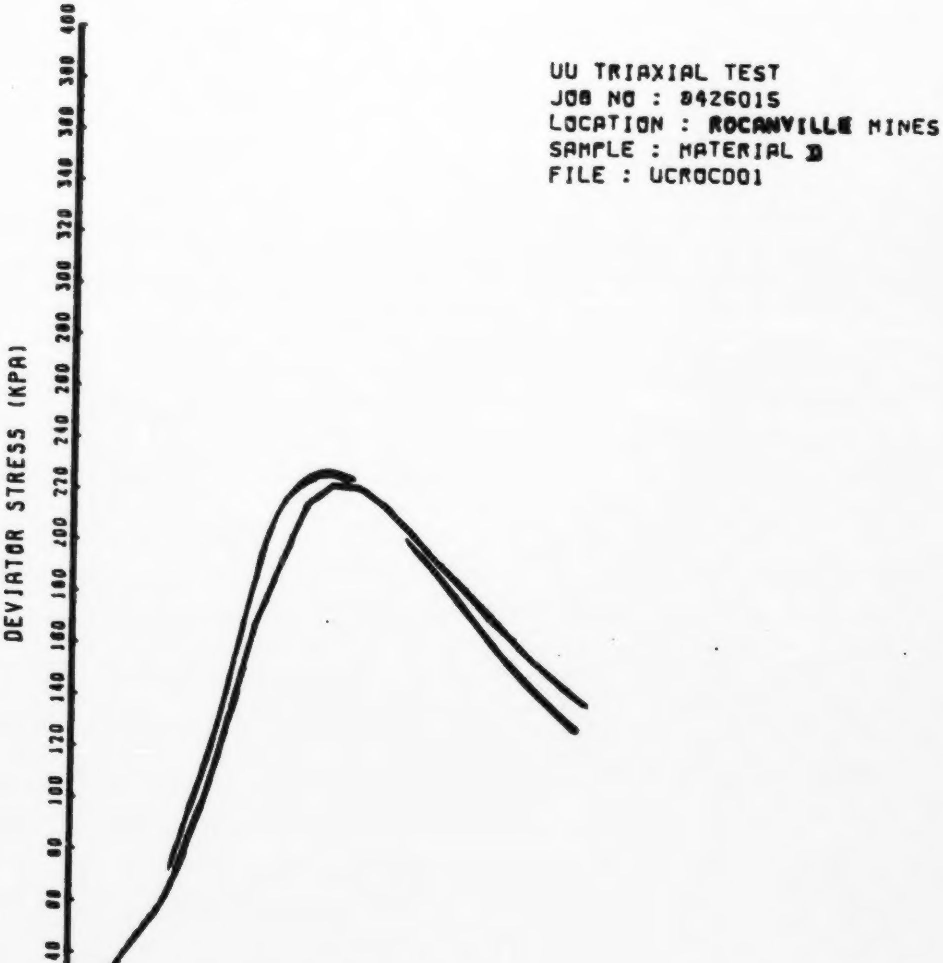
LOCATION : ROCANVILLE MINES
SAMPLE : C
FILE : UCROCC01
CURING TIME 72 HOURS

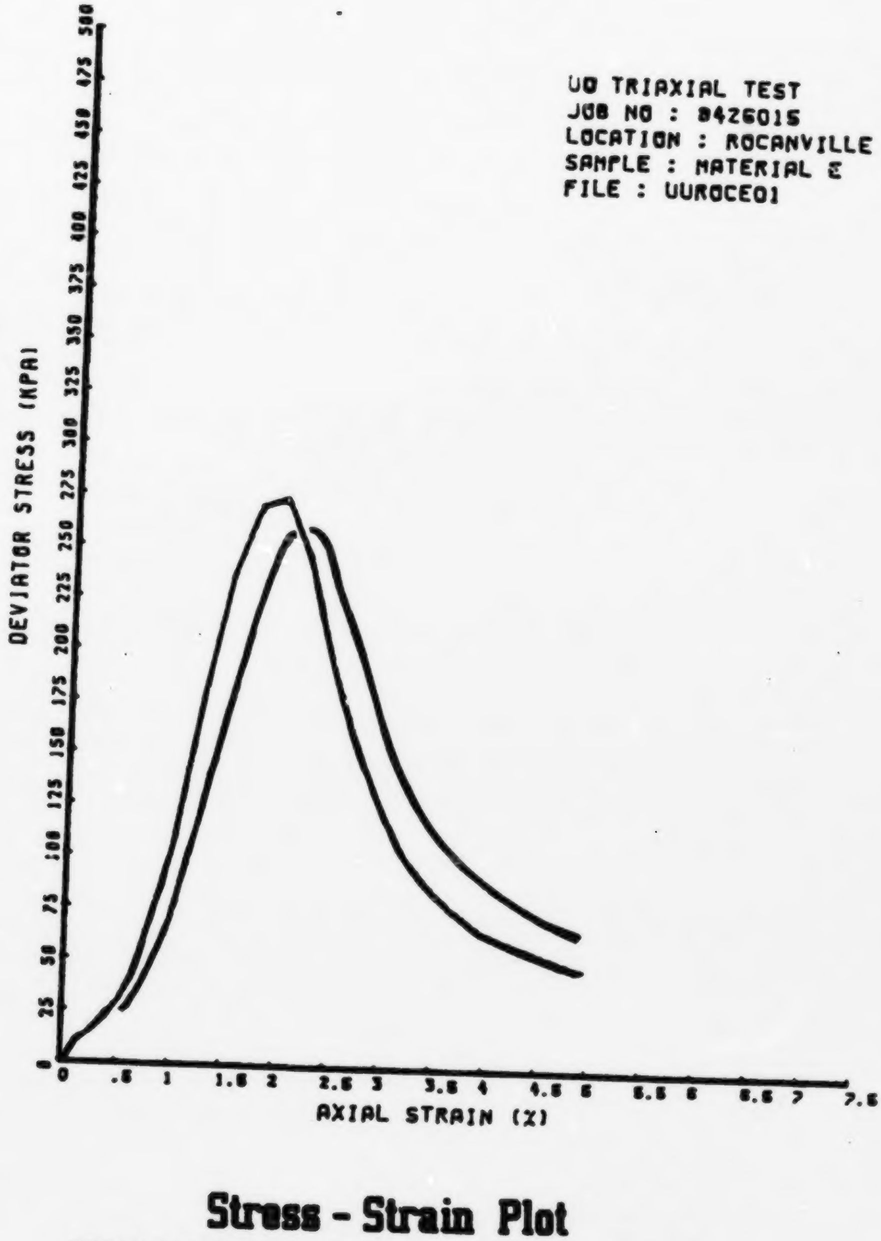
Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 20



Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4   21



Stress - Strain Plot
UNCONFINED COMPRESSION TEST

Drawing 4 22

APPENDIX B

LITERATURE REVIEW

PCS Mining
A subsidiary of the Potash Corporation of Saskatchewan

B-1.0 INTRODUCTION

The sylvinite ore mined in conventional mines in Saskatchewan contains approximately 50% halite (sodium chloride), 45% sylvite (potassium chloride) and from two to five percent water insolubles. The water insoluble material is present primarily as thin stratigraphic layers throughout the ore zone.

Generally the beneficiating process involves the following stages of separation. The ore is crushed and ground in brine saturated in KCl and NaCl. Insolubles are separated and removed by physical and chemical methods. Sylvite is then separated from the halite in the deslimed ore by mechanical means. The product (KCl) is then processed, sized and debrined.

The water insolubles are purged from the system as waste as underflow from the slimes thickener. Along with the water insolubles, some of the re-circulating brine and halite (NaCl) is also discharged in the slimes thickener underflow. The combined discharge referred to as slimes herein is thus comprised of water insolubles (10-60%) and salt crystals (40-90%) slurried in a saturated brine solution.

The other intentional discharge from the potash beneficiating process is the solid sodium chloride tails which have been separated from the potassium chloride in the flotation process. Conventionally, the salt tails are then mixed with the underflow from the slimes thickener, slurried in brine and pumped by a pipeline to the tails pile.

Thus, the materials generated may be categorized as follows:

- clay (water insoluble) seam in the ore bodies
- water insolubles
- slimes
    - mixture of water insolubles and salt tails
- halite (NaCl)

- mixture of slimes and salt crystals as slurried for discharge to the tails pile,
  - 4 to 10% insolubles
  - 90 to 96% salt crystals

The limited studies of engineering properties completed to date have dealt with one or more of the above and can generally be categorized under the following headings:

- Mineralogy of clay seams in the sylvinite ore bodies
- Physical and chemical properties of slimes and water insolubles
- Physical and chemical properties of salt tails

B-2.0 REFERENCE STUDIES

B-2.1 Introduction

Extremely limited information is available related to the engineering properties of waste slimes or salt tails produced at Saskatchewan potash mines. The only published data available relates to studies of the mineralogy of the water insolubles. For this study, the sole source of existing data pertaining to the engineering properties of the waste products was PCS Mining, through either contract research or consultants commissioned for specific tasks. A listing of the studies available is given below with a detailed summary of the data pertinent to this project given in the following sections.

B-2.2 Selected References - Mineralogy of Clay Marker Seams

Dean, R.S., (1971). Clay Mineralogy of a Sample of Sylvite Ore from the Duval Corporation Mine, Saskatoon, Sask., Canada, DEMR Mines Branch Investigation Report IR-71-19.

Dean, R.S., (1978). Clay Mineralogy of Sylvite Ore from the Allan Potash Mines, Allan, Sask., CANMET Mineral Sciences Laboratories Report MRP/MSL 78-192 (TR).

Mossman, D.J., R.N. Delabio and A.D. Mackintosh, (1982). Mineralogy of Some Clay Marker Seams in Some Saskatchewan Potash Mines, Canadian Journal of Earth Sciences, Vol. 19, p.p. 2126-2140.

B-2.3 Selected References - Composition of Slimes

PCS Mining (1977-1984). Project and Operating files.

Arnold, R., (1981). Report on X-ray Diffraction Study of Water Insolubles in Cory Ore. SRC Publication No. G-748-1-C-81.

Saskatchewan Research Council (1982). Report of Mineralogical Analyses of Water Insoluble Portion of Slimes Samples taken from PCS Mining Divisions, Conducted Under Contract to PCS Mining. Unpublished.

B-2.4 Selected References Composition of Salt Tails

PCS Mining (1977-1984). Operating Files, Environmental Affairs Section.

B-2.5 Selected References-Physical Properties of Slimes

Pufahl, D.E., (1983). Strength Testing of Potash Slimes from PCS Mining Lanigan Division. Unpublished study conducted by the University of Saskatchewan Geotechnical Group.

Bromwell Engineering (1983). Selected Tests of Processed Slimes at PCS Mining Cory Division. Report prepared under contract to PCS Mining Cory Division.

BBT Geotechnical Ltd (1983). Selected Testing of Potash Slimes Sampled at PCS Mining Allan, Cory, Lanigan and Rocanville Divisions. Report prepared under contract to PCS Mining.

B-2.6 Selected References - Physical Properties of Salt Tails

University of Saskatchewan Geotechnical Group

- Pufahl and Yosheda (1982). Study of Potash Tailings Properties and Behavior for Total Extraction Mining. Research Report conducted under a contract to PCS Mining Research and Development.

- Pufahl and Loi (1984). Study of Elastic Parameters of Potash Tailings, PCS Mining Rocanville Division. Research Report conducted under contract to PCS Mining Research and Development.

Golder Associates, (1977). Geotechnical Studies of Tailings Pile Stability at PCS Mining Cory Division. Report prepared under contract to PCS Mining.

Golder Associates, (1983). Field Investigation for Research. Slope Stability and Hydrogeological Evaluation-PCS Mining Lanigan Division. Report prepared under contract to PCS Mining.

B-3.0 MINERALOGY OF CLAY MARKER SEAMS

B-3.1 Dean (1971)

Dean (1971) undertook a study of the clay mineral fraction of a sample of ore containing a "grey clay seam". A mineralogical analysis was attempted using XRD techniques and was presented in qualitative terms only. The report concluded that:

> "1) The grey "clay" seam within the Duval sylvite ore sample consists principally of anhydrite, with lesser halite and sylvite. Quartz, clay minerals and dolomite occur in decidedly smaller quantities.
>
> 2) The clay mineral fraction within both the grey seam and the insoluble residue of the coarse red salt consists of roughly equal proportions of four phases: illite, chlorite, septechlorite and vermiculite. Chlorite, septechlorite and probably, vermiculite are trioctahedral.
>
> 3) The septechlorite and vermiculite are possibly of authigenic origin. The septechlorite has a high thermal stability, hence it is probably rich in magnesium. The vermiculite is very readily decomposed by hydrochloric acid."

B-3.2 Dean (1978)

Dean (1978) examined the cold water residues of the clay seams and sylvite ore from the "B-zone" of the Allan potash mine (now PCS Mining Allan Division). Dean states that the results of this study agreed closely with unpublished SRC analyses of the "A-Zone" water insoluble fraction at Allan. The results are similar to the Duval study reported by Dean (1971).

The samples were found to contain as major constituents (in decreasing order of abundance):

- -Clay minerals
    - -illite
    - -chlorite
    - -septechlorite
    - -mixed layer chlorite-smectite
- -Dolomite
- -Quartz
- -Hemalite and K-feldspar (minor amounts)
- -Anhydrite (trace)

The analysis was conducted in qualitative terms only and no attempt was made to quantify the constituents.

B-3.3 Mossman et al (1982)

Mossman et al (1982) studied the water insoluble constituents and clay mineralogy using samples taken from clay seams within the ore at four different mines:

- -Cominco (Vanscoy)
- -Central Canada Potash (Colonsay)
- -PCS Mining Allan Division
- -PCS Mining Lanigan Division

The analyses were carried out in qualitative terms with no attempt to quantify the constituents. The following conclusions were drawn in the report:

a) The main clay minerals are illite, Fe-Mg 14A (1.4 nm) chlorite and septechlorite; sporadically developed accessories include sepiolite, smectite, mixed layer chlorite-smectite and probably vermiculite. Illite and 14A (1.4 nm) Fe-Mg chlorite are most likely detrital in origin; the Mg-rich clay minerals and possibly also the potassium feldspar, may have originated under hypersaline conditions in the original evaporite basin and (or) developed diagenetically.

b) Non-clay water-insoluble constituents are, in order of relative abundance, anhydrite, dolomite, hematite, quartz, potassium feldspar, hydrocarbon, (primitive) palynomorphs and magnetite. It has not proven possible to fingerprint individual clay seams on a strict basis using mineralogy or paleontology. However, as a group the clay seams are useful for regional stratigraphic correlation with the area studied.

c) Indications are that the proportions and kinds of clay minerals in the ore zones of the Prairie Evaporite directly reflect the extent to which saline-hypersaline conditions were developed.

B-4.0 COMPOSITION OF WASTE SLIMES

B-4.1 Bulk Samples

As the water insolubles are separated and discharged as underflow from the slimes thickener, they are accompanied by salt crystals. Thus, the purged "slimes" consist of a mixture of salt crystals and water insolubles. Data available within the PCS Mining Environmental Affairs Section files indicate that typical slimes consist of:

1) 10% to 60% water insolubles (by weight)
2) 40% to 90% salt crystals (by weight)

The bulk composition of the purged slimes is variable and is dependent upon the quality of ore being processed.

B-4.2 Arnold (1981)

Arnold (1981) attempted to analyze the mineralogical composition of the water insoluble portion of various samples of slimes and salt tails obtained from the mill at PCS Mining Cory Division. The water insolubles were separated and the constituents were analyzed qualitatively with no attempt to convert x-ray diffraction line intensities into mass concentrations of minerals present.

The report concluded that the water insoluble portion of the slimes consisted mainly of dolomite and quartz with smaller amounts of anhydrite, illite and kaolite present. Based on the work of Dean (1971, 1978) and Mossman et al (1982), there is strong evidence that the report of kaolinite by Arnold is in fact a mis-identification of septechlorite.

B-4.3 Saskatchewan Research Council (1982)

In 1982, PCS Mining Environmental Affairs Section obtained bulk samples of slimes from all four operating divisions of PCS Mining (Cory, Rocanville, Lanigan and Allan) and contracted the Saskatchewan Research Council to conduct x-ray diffraction analyses on the water insoluble portion of representative samples. A total of seven to nine samples were analyzed for each site. The SRC provided a quantitative analysis based on peak intensities of the x-ray diffraction. Results are summarized in Table B-4.1

TABLE B-4.1

SUMMARY OF MINERALOGICAL ANALYSES OF POTASH SLIMES FROM PCS MINESITES

Mineralogical Content in %	Allan Div		Cory Div		Lanigan Div		Rocanville Div	
	Average	Range	Average	Range	Average	Range	Average	Range
Quartz	17	14-20	19	15-21	23	18-26	22	18-27
Kspar/Microcline	9	2-14	1	0-2	6	5-8	5	0-10
Plagioclase	0	---	6	3-8	0	---	2	0-5
Calcite	2	2-4	2	2-3	2	1-2	3	1-4
Dolomite	15	13-20	17	12-20	12	12-13	34	31-38
Siderite	0	---	0	---	0	---	0	---
Pyrite	0	-	0	---	0	---	0	---
Gypsum	1	0-1	0	---	1	0-4	1	0-1
Anhydrite	6	2-9	2	0-8	4	3-6	13	8-17
Illite	26	16-35	27	21-38	29	23-33	13	10-18
Chlorite	6	3-8	7	2-9	5	5-6	2	1-3
Septechlorite	18	13-28	19	16-22	18	12-21	8	4-12
Montmorillonite	0	---	0	---	0	---	0	---
Mixed Layer Clays	0	---	0	---	0	---	1	0-1
Total % Clays	50		53		52		23	
No. of samples	9		9		7		8	

Notes: -Analyses by the Saskatchewan Research Council

-All samples obtained June to September, 1982

B-5.0 COMPOSITION OF SALT TAILS

Samples of salt tails referred to herein were obtained from the mill prior to slurrying with slimes and pumping to the waste pile.

B-5.1 PCS Mining, Environmental Affairs Section (1982)

PCS Mining Environmental Affairs Section had chemical analyses performed on samples of salt tails obtained from each of the four operating divisions in 1982. The samples were oven dried and ground before analyses. A portion of those samples were dissolved in water and an analysis performed for major ions. An analysis of the total salt tails sample (not dissolved) was performed for minor element determination. The following results were obtained.

	Water Soluble					
	% K^+	% Na^+	% Mg^{++}	% Ca^{++}	% CI^-	% $SO_4^=$
Rocanville Tails	3.38	36.40	.014	.050	59.17	.073
Lanigan Tails	1.84	37.49	.096	59.39	.203	.203
Allan Tails	1.52	37.65	.031	.137	59.32	.296
Cory Tails	2.37	36.78	.039	.142	58.76	2.96

	Total Sample							
	PPM Br	PPM Sr	PPM Rb	PPM Ti	PPM Fe	PPM Al	PPM Si	% WI	150°C H_2O
Rocanville Tails	132	5	10	10	70	150	472	.36	.048
Lanigan Tails	171	15	10	27	239	331	1 200	.72	.024
Allan Tails	140	18	10	31	238	340	1 299	1.01	.088
Cory Tails	52	11	10	26	228	343	1 334	1.05	.114

Typical waste salt tails at PCS Mining Cory Division and Rocanville Division are made up as follows:

1) PCS Mining Cory Division

    $NaCl$ - 97-99%
    KCl - 0.25-0.50%
    Insol - 0.50-1.25%

2) PCS Mining Rocanville Division

    $NaCl$ - 95-96%
    KCl - 2-3%
    Insol - 0.25-0.5%
    $MgCl_2$- 1.25-2.0%

B-6.0 PHYSICAL PROPERTIES OF WASTE SLIMES

Very little data has been published documenting the engineering properties of slimes or water insolubles. Available information is restricted to limited testing initiated by PCS Mining in very recent years.

B-6.1 Bromwell Engineering (1983)

Bromwell Engineering Inc., Lakeland, Florida performed classification tests on a sample of waste slimes obtained from PCS Mining Cory Division. The test performed included:

1) Density of pore fluid
2) Solids content (as received sample)
3) Fraction finer than No. 200 sieve
4) Atterberg Limits (minus No. 200 material)

Because the pore fluid was super saturated and salt was present both as crystals and dissolved in the water, the liquid limit test was performed by centrifuging and draining the slurry down to the liquid limit to avoid adding salt crystals to the samples during a drying process. The samples were partially dried for the plastic limit test. Moisture content determinations were adjusted to numerically deduct the salt that crystallized during the oven-drying, yielding the following definitions:

w/c (unadjusted) = $W_{water}/(W_{dissolved\ salt} + W_{salt\ crys} + W_{soil})$

W/C (adjusted = $W_{water}/(W_{salt\ crys} + W_{soil})$

The Bromwell report indicates that the Atterberg Limits were determined using only material passing the No. 200 sieve. Thus, a major portion of the salt crystals component of the original sample were removed for this test.

The results obtained by Bromwell are summarized as follows:

Density of pore fluid ---------------------- 1.42 gm/cm^3

Solids content (as received) -------------- 53%

Fraction finer than No. 200 sieve --------- 4%

Atterberg Limits (minus No. 200 sieve)

	Unadjusted	Adjusted
Liquid Limit	36	42
Plastic Limit	18	19
Plasticity Index	18	23

B-6.2 BBT Geotechnical Consultants Ltd. (1983)

A number of physical tests were attempted on samples of slimes recovered from the four operating divisions during 1982. These samples corresponded to the samples on which mineralogical analyses were conducted by the Saskatchewan Research Council (1982).

Samples of slimes obtained from the mill thickener underflow were subjected to physical tests as sampled (water insolubles plus salt crystals) and with the salt crystals removed (water insolubles only).

The samples as obtained from the sites consisted of salt crystals and water insolubles in the approximate proportions as follows:

PCS Mining Cory Division	60% salt 40% W.I.
PCS Mining Lanigan Division	45% salt 55% W.I.
PCS Mining Allan Division	45% salt 55% W.I.
PCS Mining Rocanville Division	80% salt 20% W.I.

One set of test samples was prepared in the above proportions while a duplicate set of samples was prepared by washing out all of the salt crystals, leaving only water insolubles.

The following series of tests were then performed on the duplicate samples (washed and unwashed):

1) water content (unadjusted as received, unwashed samples only)
2) liquid limit test
3) plastic limit test
4) shrinkage limit test
5) specific gravity test
6) moisture density relationship (Standard Proctor Compaction Test)
7) unconfined compression tests
8) consolidation tests
9) grain size by hydrometer

The materials testing laboratory of BBT Geotechnical used Standard ASTM soil testing procedures for all samples. This provided reliable data for the washed slimes samples (water insolubles only) however, produced very erratic and unreliable results for those samples containing salt crystals. The greatest error was introduced by the addition of distilled water as called for in standard soil testing specifications and the subsequent dissolving of salt crystals.

A quantitative analysis of clay content (by x-ray diffraction) was performed by the Saskatchewan Research Council on duplicate samples (see Section B-4.3).

Data is summarized in the attached tables and graphs, as either extracted from the BBT report or prepared by PCS Mining from data contained in the BBT report.

The insoluble portion of the slimes classify as low to medium plastic clay (CL-CI). Samples from the Cory and Allan minesites exhibit the highest plasticity (CI) with samples from the Rocanville minesite exhibiting the lowest plasticity (CL). This is consistent with the measured clay content.

General relationships are clearly indicated by the data. Relationships can be established between the Atterberg Limits, the optimum water content, the maximum dry density and the clay content. These relationships follow generally expected trends and indicate that the water insolubles exhibit index characteristics somewhere between what would be expected of illite and kaolinite.

TABLE I

PHYSICAL TEST RESULTS

Sample Test Determination Mine Location	Date	Unwashed W(%)	LL	PL	PI	SL	Gs	MDD	OMC%	Washed LL	PL	PI	SL	Gs	MDD	OMC%	Total Clay Content (%)
Allan	June 11/82	~~[illegible].6~~	~~20~~	~~14~~	~~6~~	~~27.0~~	~~2.77~~	~~1734~~	~~12.[illegible]~~	42	24	18	17.2	2.74	1660	19.8	54
Allan	June 21/82	~~55.[illegible]~~	~~21~~	~~14~~	~~7~~	~~27.5~~	~~2.81~~	~~1681~~	~~[illegible].4~~	45	24	21	20.9	2.84	1637	22.4	48
Allan	June 25/82	~~58.4~~	~~[illegible]0~~	~~14~~	~~6~~	~~27.4~~	~~2.93~~	~~17[illegible]~~	~~10.3~~	43	23	20	19.7	2.75	1645	18.6	48
						*											
Cory	Sept. 27/82	~~43.2~~	~~18~~	~~[illegible]~~	~~2~~	~~23.9~~	~~3.0[illegible]~~	~~1704~~	~~11.9~~	30	21	9	23.0	2.87	1748	18.0	37
Cory	Sept. 28/82	~~42.8~~	~~18~~	~~15~~	~~[illegible]~~	~~24.6~~	~~[illegible]89~~	~~1718~~	~~12.1~~	41	22	19	25.3	2.82	1693	20.5	64
Cory	Sept. 30/82	~~40.5~~	~~18~~	~~15~~	~~3~~	~~22.[illegible]~~	~~2.88~~	~~1739~~	~~10.8~~	40	20	20	21.0	2.78	1679	21.4	53
Lanigan	Oct. 7/82	~~43.1~~	~~20~~	~~15~~	~~5~~	~~[illegible]3.[illegible]~~	~~2.84~~	~~1716~~	~~21.1~~	37	21	16	20.8	2.75	1678	18.6	56
Lanigan	Oct. 13/82	~~51.0~~	~~24~~	~~17~~	~~[illegible]~~	~~29.1~~	~~[illegible]02~~	~~1680~~	~~13.9~~	40	22	18	20.2	2.82	1627	20.6	52
Lanigan	Oct. 20/82	~~42.2~~	~~21~~	~~1[illegible]~~	~~6~~	~~26.2~~	~~2.7[illegible]~~	~~1723~~	~~12.0~~	32	19	13	28.6	2.93	1706	17.7	48
Rocanville	Oct. 5/82	~~24.5~~	~~[illegible]~~	~~14~~	~~1~~	~~27.2~~	~~3.00~~	~~159[illegible]~~	~~10.0~~	30	18	12	24.2	2.77	1832	14.0	25
Rocanville	Oct. 7/82	~~24.[illegible]~~	~~14~~	~~14~~	~~NP~~	~~22.7~~	~~2.85~~	~~1600~~	~~[illegible].1~~	29	18	11	18.3	2.76	1783	16.8	22
Rocanville	Oct. 19/82	~~[illegible].3~~	~~16~~	~~16~~	~~NP~~	~~27.2~~	~~2.93~~	~~1548~~	~~11.[illegible]~~	28	18	10	23.1	2.76	1781	16.5	15

* RESULTS UNRELIABLE

TABLE II

UNCONFINED COMPRESSION TEST RESULTS

Sample Test Determination Mine Location	Date	Unwashed W %	Compacted qu-kPa	Strain %	Kneeded qu-kPa	Strain %	Washed W %	Compacted qu-kPa	Strain %	Kneeded qu-kPa	Strain %
Allan	June 21/82	12.2	155.0	14.4	64.3	4.2	19.6	323.5	11.0	735.7	6.3
Cory	Sept. 30/82	10.9	160.2	20.0	49.8	7.1	19.0	131.1	11.2	149.8	11.7
Lanigan	Oct. 13/82	13.3	97.6	17.9	99.1	20.0	18.4	264.5	3.9	163.9	3.3
Rocanville	Oct. 7/82	10.1	93.9	8.7	8.8	1.6	16.0	98.3	3.9	109.3	3.4

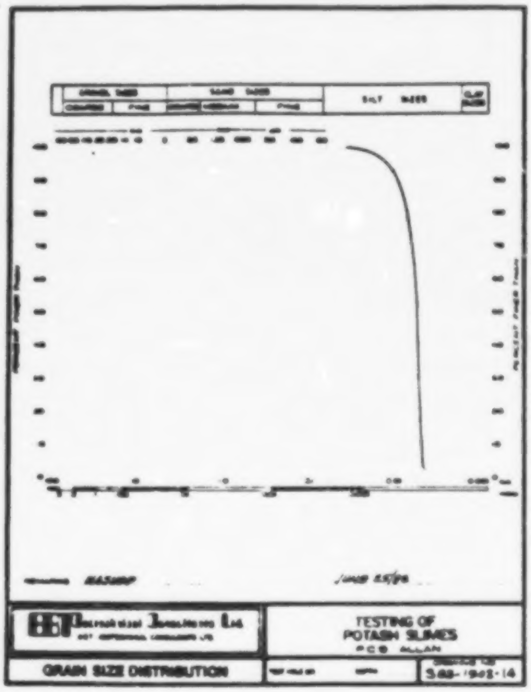
TABLE III

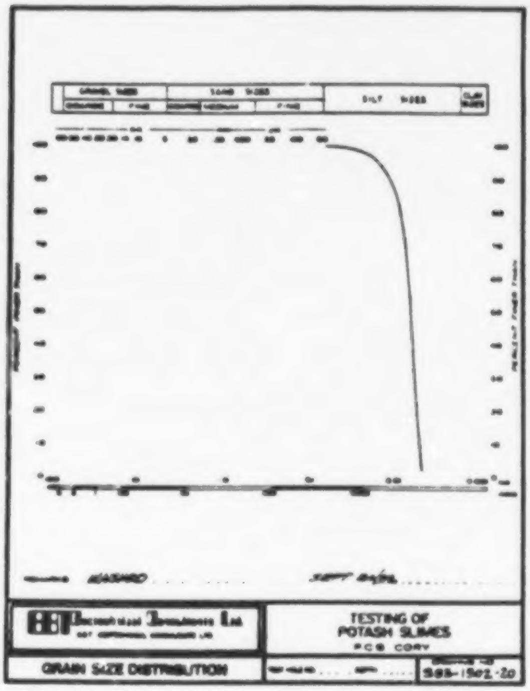
CONSOLIDATION TEST RESULTS

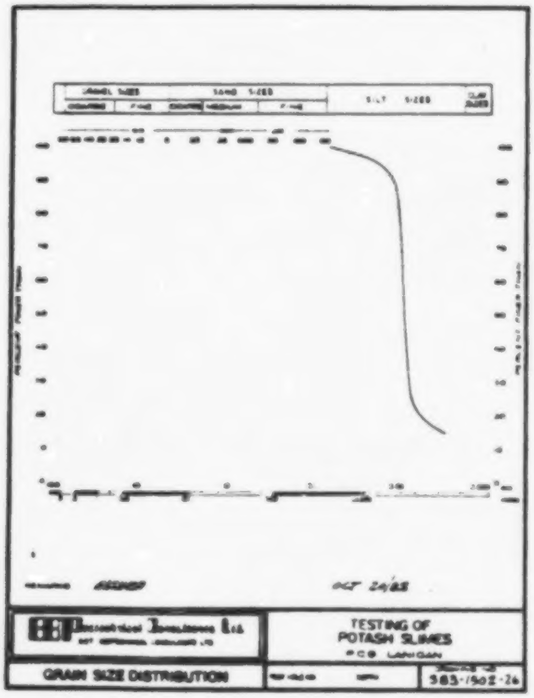
Test Determination Mine Location and Sample	Wo %	o kg/m^3	Cc(1600)	Cs(800)	Av(1600)	Mv(1600)	Cv(1600) m^2/sec.	k(1600) m^2/sec.
Allan Unwashed	~~13.5~~	~~944~~	~~0.48~~	~~0.06~~				
Allan Washed	21.8	1701	0.165	0.03	4.67×10^{-5}	3.0×10^{-5}	1.32×10^{-7}	3.88×10^{-11}
Cory Unwashed	~~10.7~~	~~666*~~	~~0.75~~	~~0.06~~				
Cory Washed	22.8	1697	0.145	0.03	4.1×10^{-5}	2.76×10^{-5}	1.147×10^{-7}	3.106×10^{-11}
Lanigan Unwashed	~~13.9~~	~~957~~	~~0.40~~	~~0.10~~				
Lanigan Washed	19.8	1689	0.155	0.025	1.132×10^{-4}	7.41×10^{-5}	1×10^{-7}	7.27×10^{-11}
Rocanville Un Washed	~~10.1~~	~~666**~~	~~1.00~~	~~0.80~~				
Rocancille ~~Un~~washed	20.4	1799	0.110	0.01	3.11×10^{-5}	2.15×10^{-5}	8.36×10^{-8}	1.766×10^{-11}

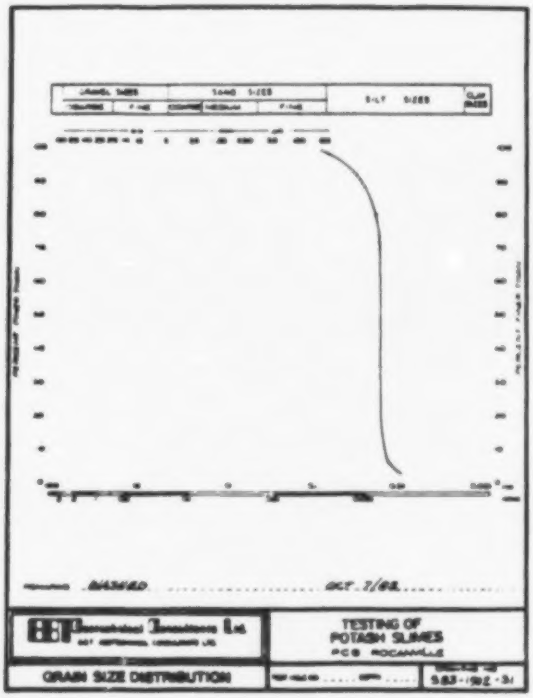
SECTION:		**LOCATION:**	**TITLE:**
SCALE:	**DATE**		**Summaries of Test Results** **Slimes Samples-1982** **(Tests by BBT Geotechnical)**
DESIGNED BY:		Potash Corporation of Saskatchewan	
DRAWN BY: P.R.	**JULY 1984**		
CHECKED BY:			
APPROVED BY:			

Figure B-6.1









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SCALE:
DATE
DESIGNED BY:
DRAWN BY: P.R. JULY 1984
CHECKED BY:
APPROVED BY:

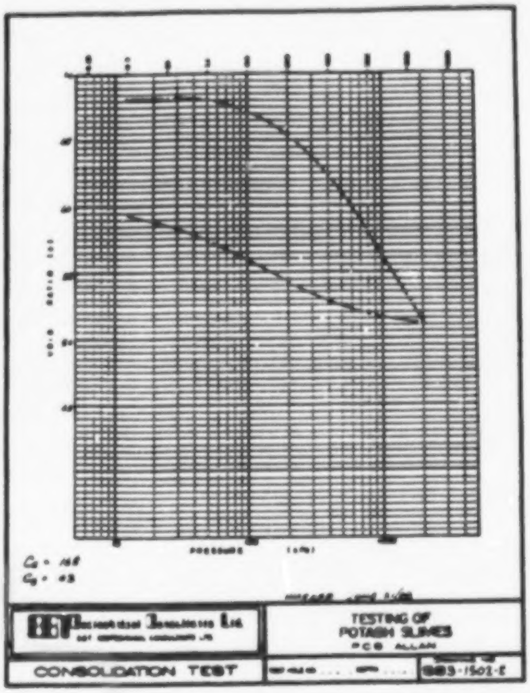
LOCATION:

Potash Corporation of Saskatchewan

TITLE:

Typical
Grain Size Distributions
Washed Slimes (Insolubles)
Sampled 1982

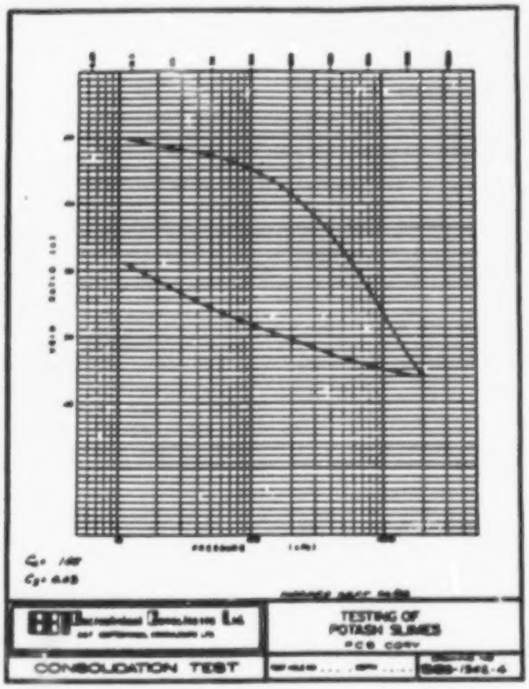
Figure B-6.2



TESTING OF POTASH SLIMES
PCS ALLAN

CONSOLIDATION TEST

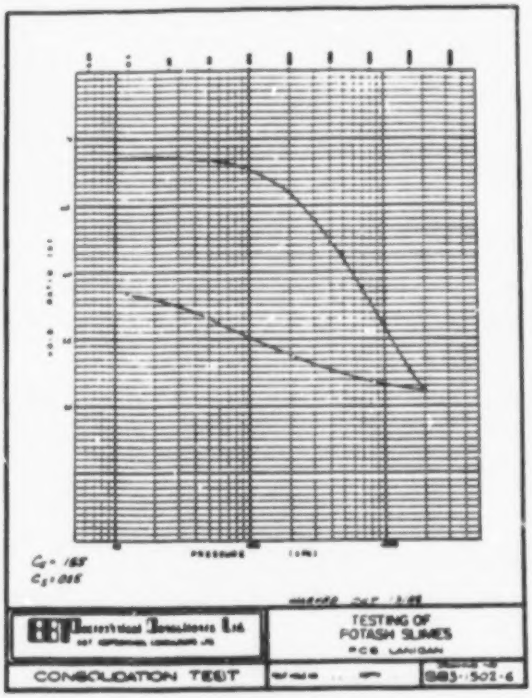
883-1502-2



TESTING OF POTASH SLIMES
PCS CORY

CONSOLIDATION TEST

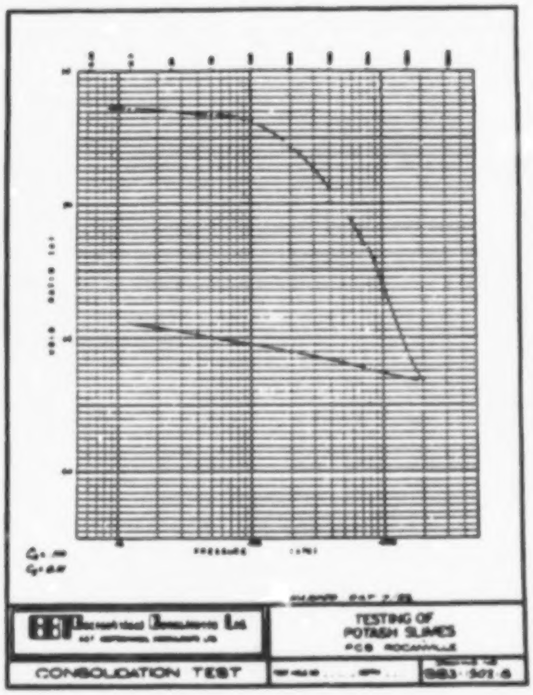
883-1502-6



TESTING OF POTASH SLIMES
PCS LANIGAN

CONSOLIDATION TEST

883-1502-6



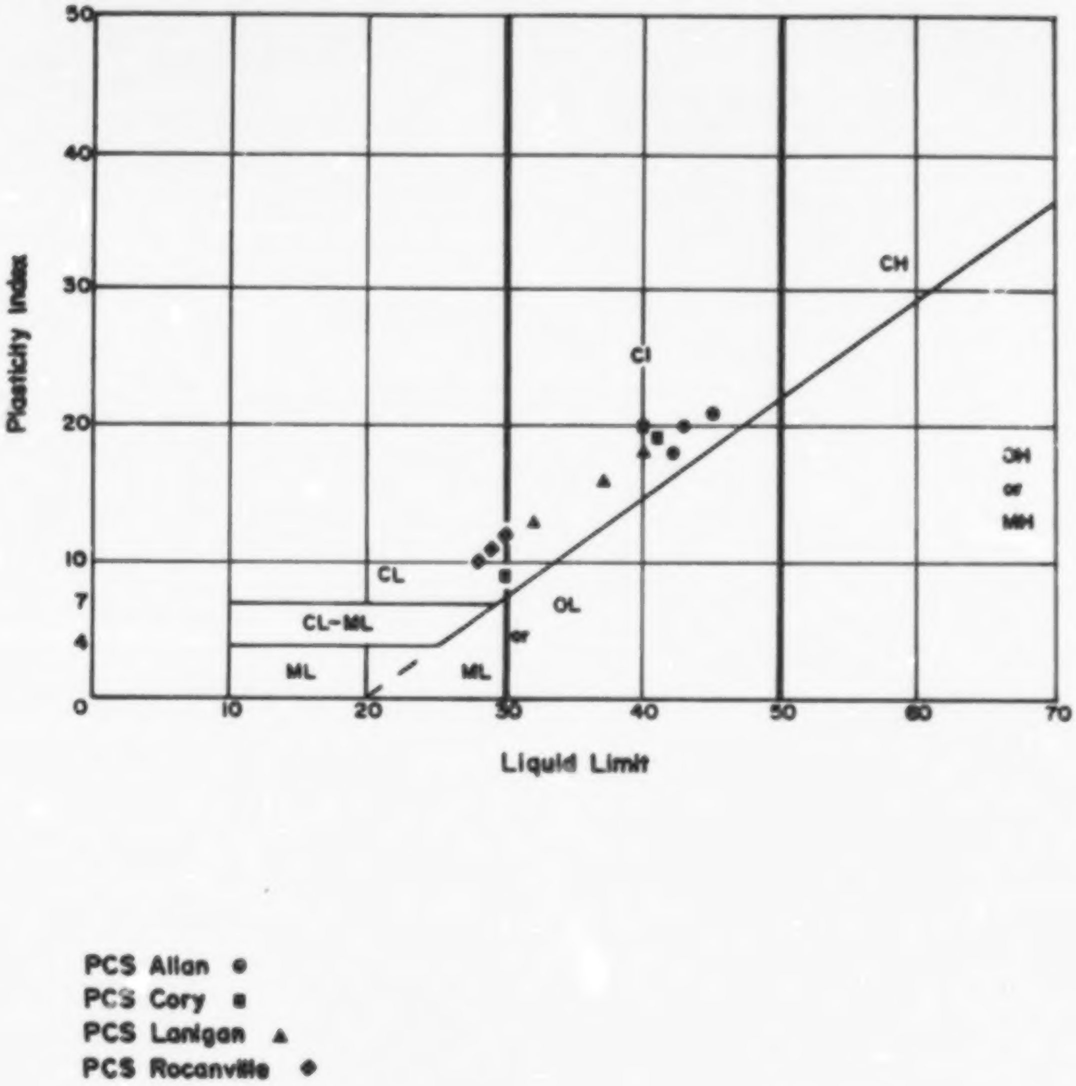
TESTING OF POTASH SLIMES
PCS ROCANVILLE

CONSOLIDATION TEST

883-1502-6

SECTION:		LOCATION:	TITLE:
SCALE:	DATE		Consolidation Test Results Washed Slimes (Insolubles) Sampled 1982
DESIGNED BY:			
DRAWN BY: PR	JULY 1984	Potash Corporation of Saskatchewan	
CHECKED BY:			
APPROVED BY:			

Figure B-6.3



SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY: PR	JULY 1984
CHECKED BY:	
APPROVED BY:	

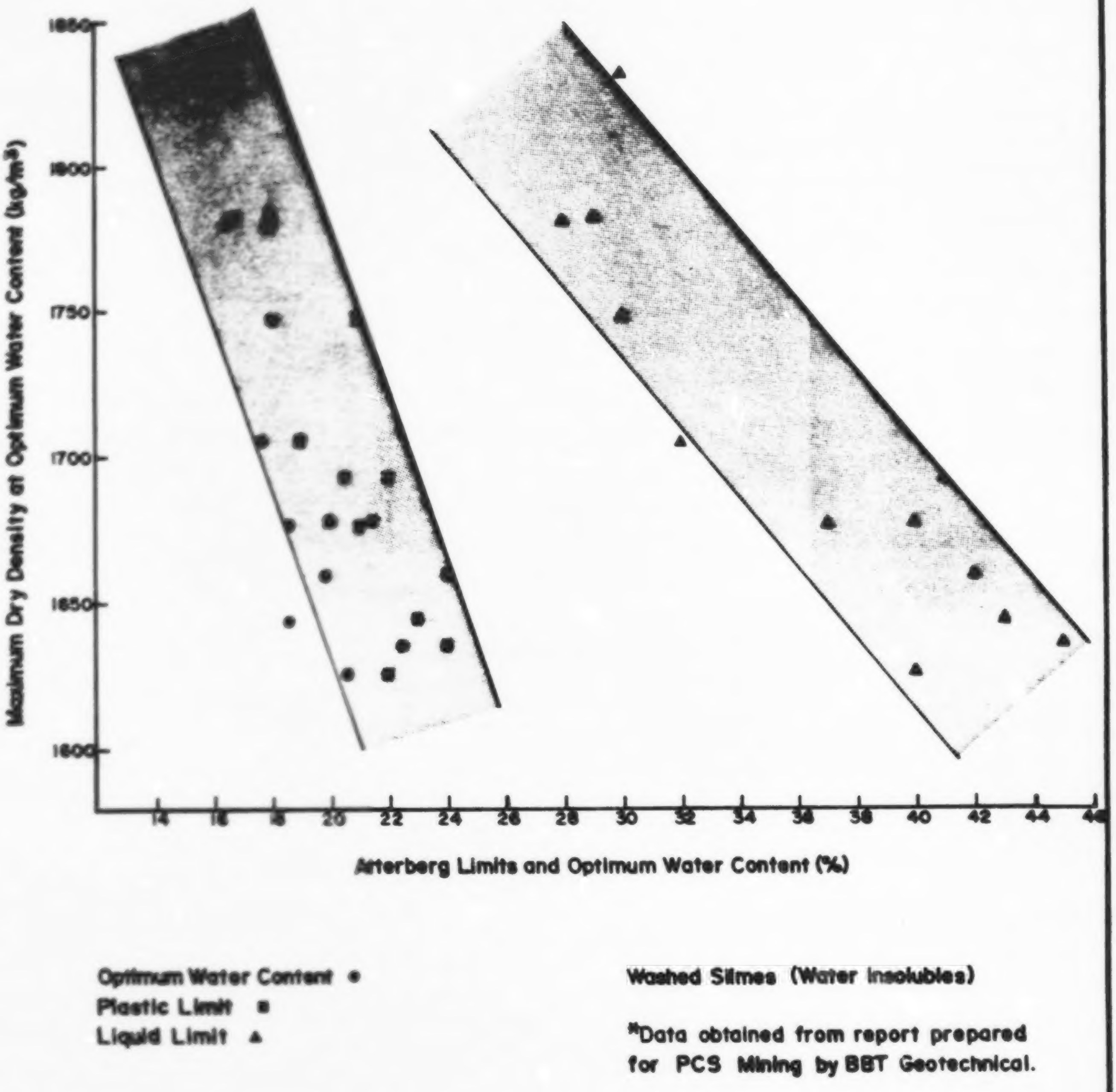
LOCATION:

Potash Corporation of Saskatchewan

TITLE:

Slimes Samples-1982
Plasticity Chart for
Water Insolubles

Figure B-6.4



Washed Slimes (Water Insolubles)

*Data obtained from report prepared for PCS Mining by BBT Geotechnical.

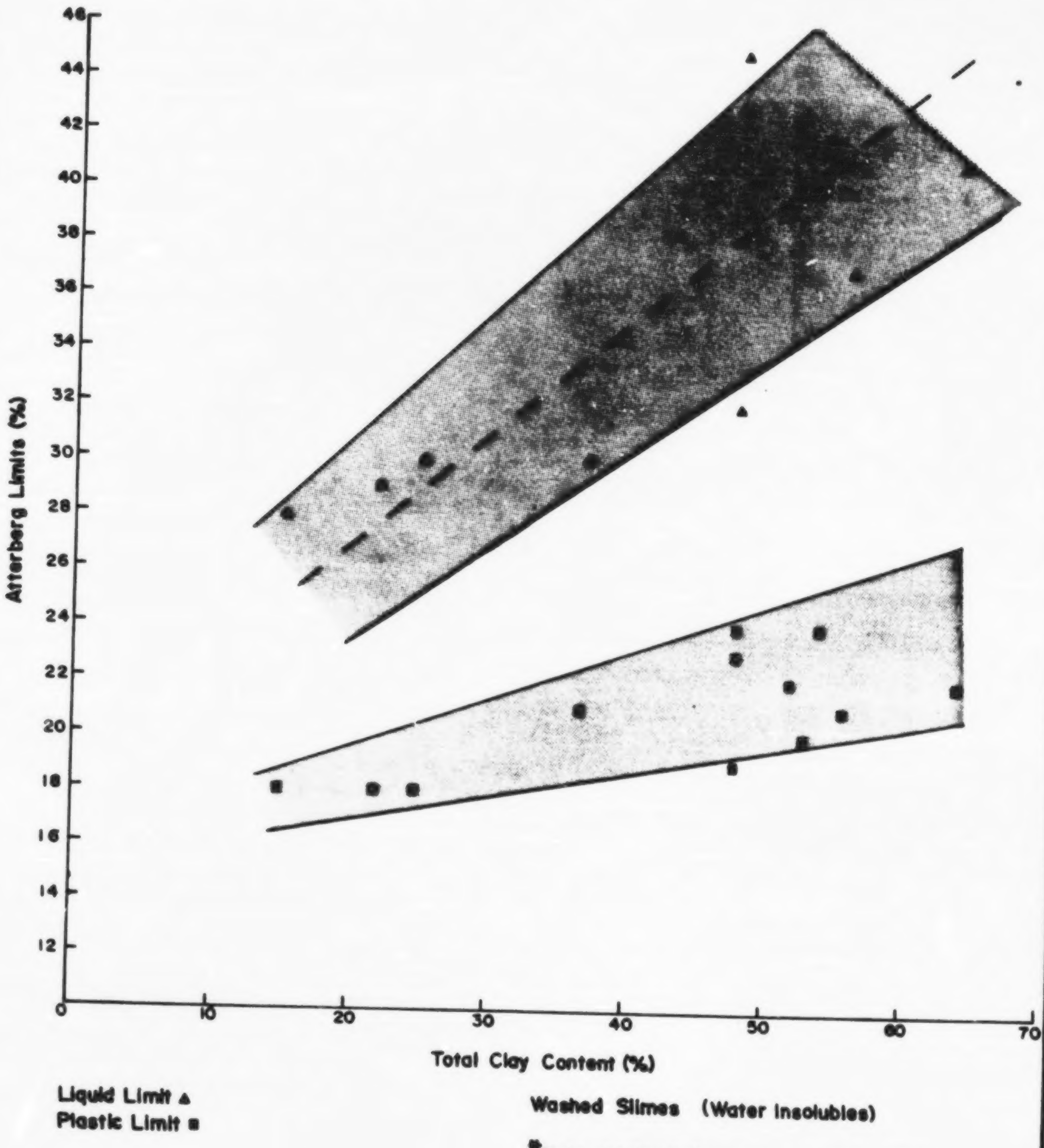
SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY: PR	JULY 1984
CHECKED BY:	
APPROVED BY:	

LOCATION:

Potash Corporation of Saskatchewan

TITLE:
Maximum Dry Density vs. Atterberg Limits and Optimum Water Content-Water Insoluble Portion of Slimes Sampled-1982

Figure B-6.5

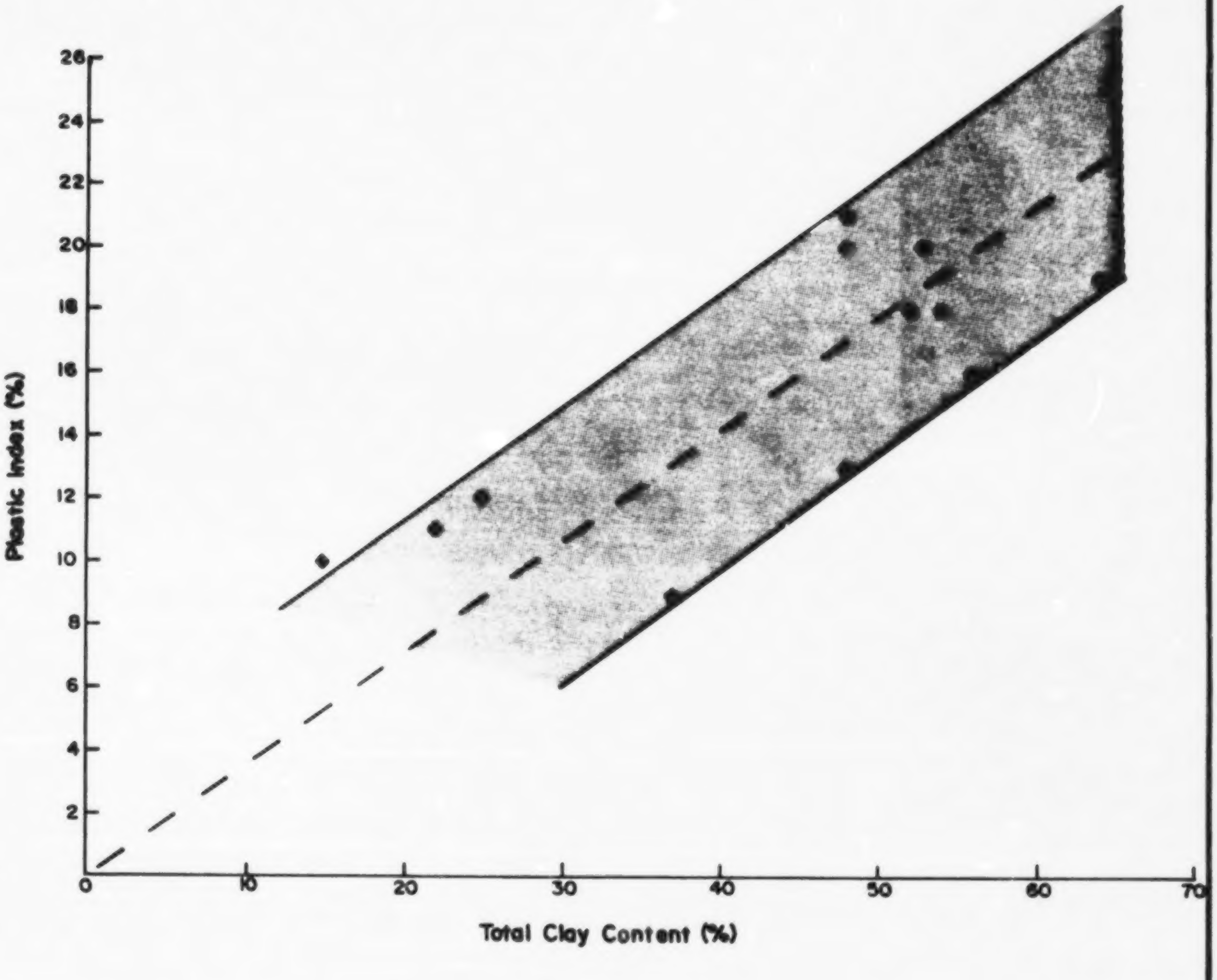


Washed Slimes (Water Insolubles)

*Data obtained from report prepared for PCS Mining by BBT Geotechnical.

SECTION:		LOCATION:	TITLE:
SCALE:	DATE		Atterberg Limits vs. Total Clay Content - Water Insoluble Portion of Slimes Sampled-1982
DESIGNED BY:			
DRAWN BY: PR	JULY 1984	Potash Corporation of Saskatchewan	
CHECKED BY:			
APPROVED BY:			

Figure B-6.6



Washed Slimes (Water Insolubles)

*Data obtained from report prepared for PCS Mining by BBT Geotechnical.

SECTION:	
SCALE:	DATE
DESIGNED BY:	
DRAWN BY:	JULY 1984
CHECKED BY:	
APPROVED BY:	

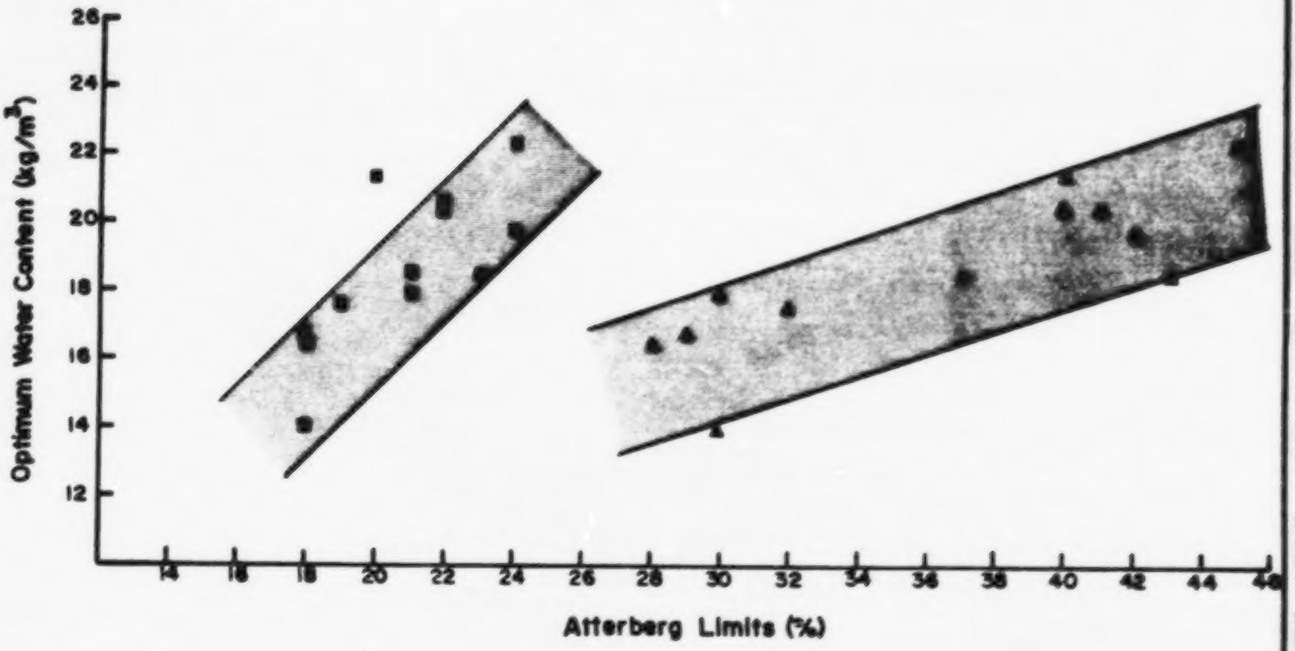
LOCATION:

Potash Corporation of Saskatchewan

TITLE:

Plastic Index vs.
Total Clay Content-
Water Insoluble Portion of
Slimes Sampled-1982

Figure
B-6.7



Plastic Limit ■

Liquid Limit ▲

Washed Slimes (Water Insolubles)

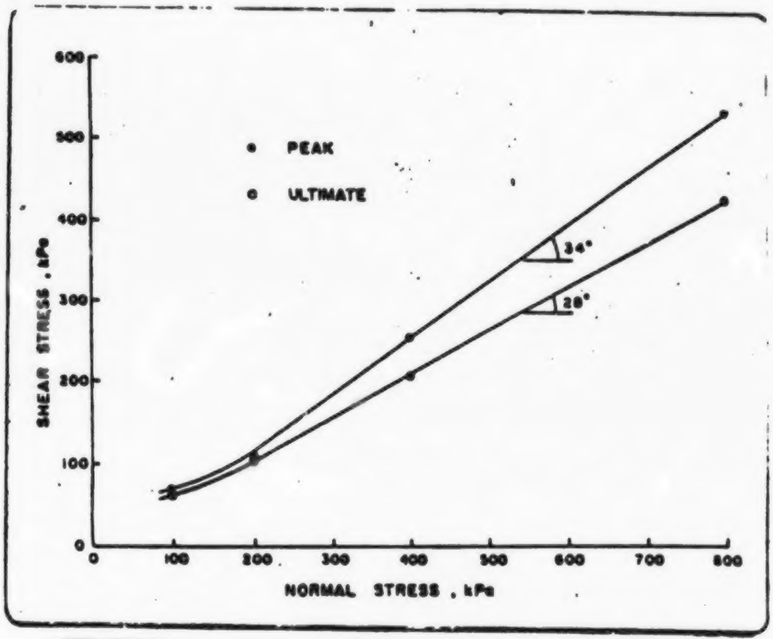
*Data obtained from report prepared for PCS Mining by BBT Geotechnical.

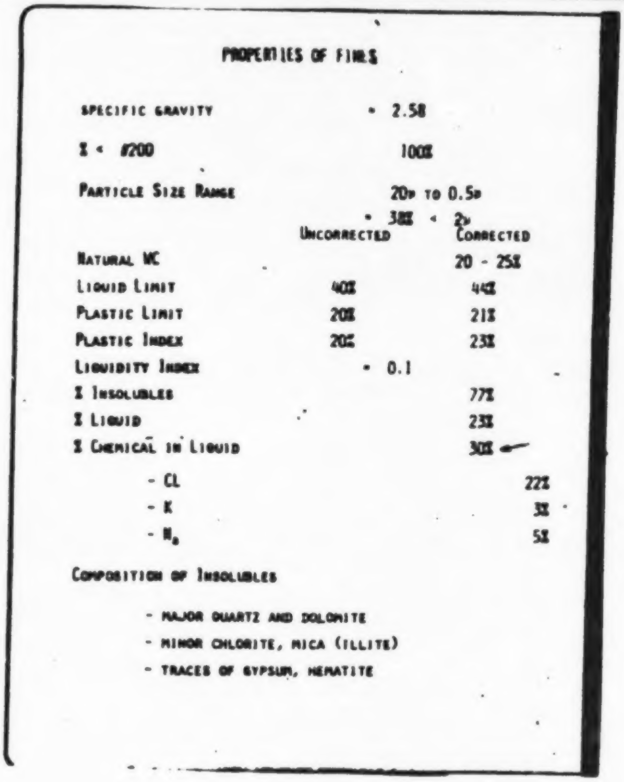
SECTION:		LOCATION:	TITLE:	
SCALE:	DATE		Atterberg Limits vs. Optimum Water Content-Water Insoluble Portion of Slimes Samples-1982	**Figure B-6.8**
DESIGNED BY:	JULY 1984	Potash Corporation of Saskatchewan		
DRAWN BY:				
CHECKED BY:				
APPROVED BY:				

B-6.3 University of Saskatchewan (1983)

During the course of conducting research on the characteristics of salt tails for PCS Mining, the U of S Geotechnical Group performed a direct shear test on one sample of slimes obtained from PCS Mining Lanigan Division (verbal communication, D. Pufahl, 1984). Only material passing the No. 200 sieve was used in the test, thus, it might be assumed that the majority of salt crystals were removed from the slimes sample. Apparently a saturated brine solution was used as the pore fluid in all tests. Water contents were corrected for dissolved salt in the fluid.

Available data are summarized on the attached plot of shear strength vs. normal stress as prepared and interpreted by the University of Saskatchewan.





PROPERTIES OF FINES

SPECIFIC GRAVITY	= 2.58	
% < #200	100%	
PARTICLE SIZE RANGE	20μ TO 0.5μ = 38% < 2μ	
	UNCORRECTED	CORRECTED
NATURAL WC		20 - 25%
LIQUID LIMIT	40%	44%
PLASTIC LIMIT	20%	21%
PLASTIC INDEX	20%	23%
LIQUIDITY INDEX	= 0.1	
% INSOLUBLES		77%
% LIQUID		23%
% CHEMICAL IN LIQUID		30% ←
- CL		22%
- K		3%
- Na		5%

COMPOSITION OF INSOLUBLES

- MAJOR QUARTZ AND DOLOMITE
- MINOR CHLORITE, MICA (ILLITE)
- TRACES OF GYPSUM, HEMATITE

Figure B-6.9
DIRECT SHEAR TEST RESULTS
SLIMES SAMPLED AT PCS MINING LANIGAN DIVISION
Tests by University of Saskatchewan (1983)

B-7.0 PHYSICAL PROPERTIES OF SALT TAILS

Limited testing has been conducted to determine the engineering properties of salt tails. Data available consists primarily of reports on PCS Mining files related to stability studies of tails piles and research work funded by the Potash Corporation of Saskatchewan and conducted by the University of Saskatchewan.

B-7.1 University of Sask-Studies of Properties and Behavior of Potash Tails (Pufahl and Yosheda,1982)

B-7.1.1 Scope of Work

Using funding provided by PCS Mining Research and Development, the University of Saskatchewan Geotechnical Group undertook studies of the engineering properties of salt tailings during the period 1981 to 1982. The research concentrated primarily on the classification of salt tails and the definition of strength and deformation parameters. The majority of tests were conducted on salt tailings sampled at the PCS Mining Rocanville Division minesite.

B-7.1.2 Sample Preparation

The majority of samples tested were prepared in the laboratory from bulk salt tails samples obtained from the plant. These samples were prepared by statically compacting a fixed mass of material at a known water content in a mold of known volume. Apparently brine was used as the mixing fluid throughout.

B-7.1.3 Chemical Analyses

Typically samples were composed of the following constituents:

$NaCl$	95-96%
KCl	2-3%
$MgCl_2$	1.5-2%
Insols	0.25-0.5%

Apparently the samples were expected to be consistent and only minimal testing of the constituents is reported.

B-7.1.4 Water Content

The U of S studies calculated water content by drying samples containing brine as the mixing fluid with no correction applied for dissolved salt in the brine, i.e.:

$$\text{water content} = W_{water}/(W_{W.I.} + W_{crys} + W_{dis})$$

This definition of water content was used throughout the U of S studies on salt tailings.

The studies concluded that the measured water content is dependent upon the total drying time permitted. The studies also concluded that there was a loss of mixing water during compaction and that if allowed to drain freely following compaction, samples would not maintain a saturated state.

B-7.1.5 Specific Gravity

The specific gravity of the salt particles was determined in accordance with ASTM except that kerosene was used instead of water. Three tests were performed giving the following values:

Trial 1	2.186
Trial 2	2.156
Trial 3	2.168
Average	2.170

The authors deemed this consistent with published literature and expected values and no further tests were performed.

B-7.1.6 Grain Size

The grain size distribution was determined on samples of salt tails as received and on samples crushed using a Los Angeles abrasion apparatus.

The uncrushed material ws found to have a uniform gradation with an effective grain size, $D_{10} = 0.78$ mm. The coefficient of uniformity, $Cu = D_{60}/D_{10}$ was found to be approximately 1.9.

Crushing the material in an L.A. abrasion machine resulted in a finer grained material with D_{10} ranging from 0.16 mm to 0.20 mm and the uniformity Coefficient, Cu, increased to approximately 8.5 to 9.0.

Blending of crushed and uncrushed material yielded a product of intermediate uniformity and grain size.

B-7.1.7 Maximum and Minimum Densities

ASTM procedures were used to determine maximum and minimum densities with the following results:

Minimum density	0.97 M_g/m^3
Maximum density	
Dry method	1.35 M_g/m^3
Wet Method	1.76 M_g/m^3

The wet method of determining maximum density yields a density approximately equal to the maximum dry density determined by the Modified Proctor test.

B-7.1.8 Moisture-Density Relationships from Dynamic Compaction

Both Standard Proctor (ASTM D-698) and Modified Proctor (ASTM D-1557) were performed. The water content vs. dry density curves for salt tails are much different than the standard curves for cohesive soils. It was found that water drained from the samples resulting in a substantial reduction from the mixing water content.

The U of S speculated that the following data may be applicable:

Uncrushed salt tails

Standard Proctor

Max. dry density	1.6 M_g/m^3
Molding water content	16.0%
Final water content	11.0%

Modified Proctor

Max. dry density	1.76 M_g/m^3
Molding water content	16-17%
Final water content	8%

Crushed Salt Tails

Standard Proctor

Max. dry density	1.65 M_g/m^3
Molding water content	10-15%
Final water content	10%

A relationship between porosity and the initial dry density was established. The effects of the addition of water insolubles on the compaction characteristics was investigated by testing samples of salt tails (both uncrushed and crushed) with 5% and 10% by weight water insolubles added. The addition of the water insolubles did not appreciably effect the maximum density attainable.

B-7.1.9 Compressibility of Salt Tails

Consolidation tests were performed by the U of S by molding specimens to a pre-determined density at a water content of 6%. The samples were not flooded but rather were tested in an unsaturated state.

The U of S concluded that the tests indicated a variability and lack of reproducibility which reflected procedural problems and that refinements of the testing procedures are required to ascertain material compressibility. It was concluded that the majority of strain occurred in the first one hundred minutes with further deflection occurring at a decreasing rate. The initial density and rate of loading will determine the rate of compression. Creep deformation occurs over a period of time and is expected to be significant.

It was postulated that initial density and rate of loading will determine the rate of compression.

B-7.1.10 Uniaxial Compression Tests

The effects of initial density, water content and "curing" or drying were investigated by the U of S. Both controlled strain and controlled stress tests were conducted.

The primary conclusion seems to be that a considerable amount of strength is available due to cementation accompanying drying. A lower water content when the specimen failed resulted in a higher strength. Specimens appeared most competent when prepared at densities greater than $1.5\ M_g/m^3$ and mixing water contents of 6 to 10%.

B-7.1.11 Direct Shear Tests

Two dimensional direct shear tests were conducted on unsaturated samples. Samples were prepared by static compaction at a water content of 5 to 6% and were not submerged during the test. The rate of deformation used in the test was 0.486 mm/min. Maximum normal stress ranges used were approximately 2 200 kPa.

The test results were interpreted as yielding the following strength parameters:

	Effective Angle of Internal Friction	Cohesion Intercept
(1) Peak	52°	100 kPa
(2) Ultimate	45°	0 kPa

B-7.1.12 Triaxial Compression Tests

Specimens were molded at a dry density of approximately 1 600 kg/m^3 and oven dried at 100°C. Equipment limitations restricted the maximum confining pressure to 827 kPa. The triaxial test data were interpreted to yield the following parameters:

Effective Angle of Internal Friction	Cohesion Intercept
53°	270 kPa

All triaxial tests performed were consolidated drained tests (CD or S).

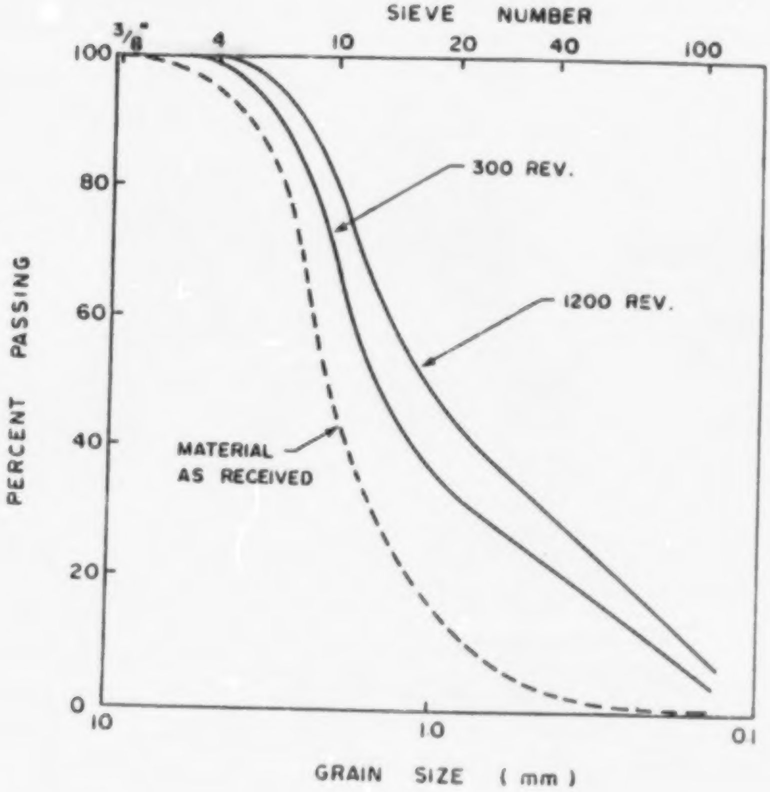


FIGURE 4.4: GRAIN SIZE CURVE FOR POTASH TAILINGS BEFORE AND AFTER CRUSHING.

GRAIN SIZE DISTRIBUTION OF TAILINGS

Revolutions in L. A. Abrasion Apparatus	% Uncrushed/ % Crushed	C_u	D_{10}(mm)
As received		1.9	0.78
300	0/100	8.8	.20
	50/50	5.4	.39
	75/25	4.0	.52
600	0/100	9.4	.17
	50/50	6.7	.29
	75/25	4.5	.48
900	0/100	8.7	.19
	50/50	6.5	.30
	75/25	4.4	.47
1200	0/100	9.0	.16
	50/50	7.0	.27
	75/25	4.7	.45

Figure B-7.1

GRAIN SIZE DISTRIBUTION - SALT TAILS

From

UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yosheda,1982)

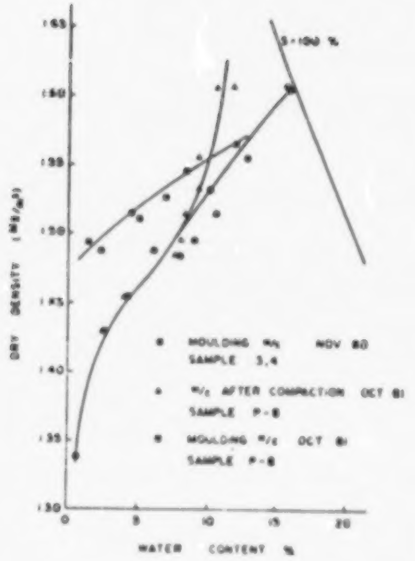


FIGURE 4.5: RESULTS OF STANDARD PROCTOR TEST.

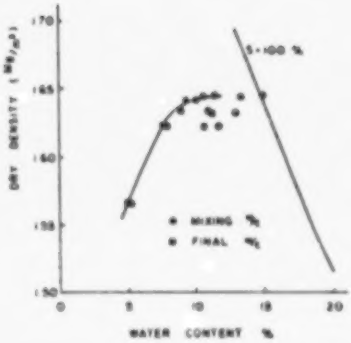


FIGURE 4.10: STANDARD PROCTOR TEST FOR CRUSHED POTASH TAILINGS. 600 REV., 0/100.

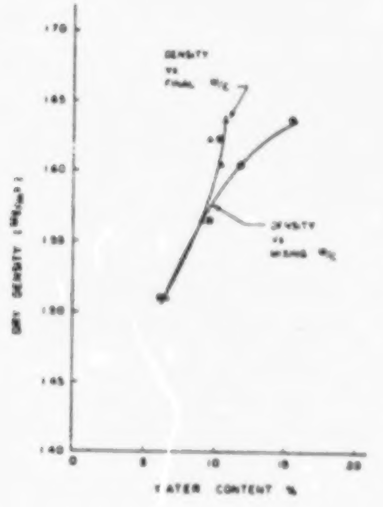


FIGURE 4.7: STANDARD PROCTOR TEST FOR MATERIAL AS RECEIVED AND 5% INSOLUBLES.

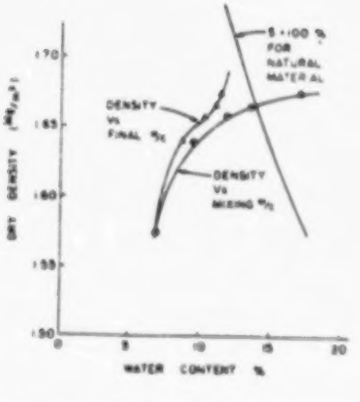


FIGURE 4.8: STANDARD PROCTOR TEST FOR MATERIAL AS RECEIVED AND 10% INSOLUBLES.

Figure B-7.2

COMPACTION TESTS - SALT TAILS

From

UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yosheda,1982)

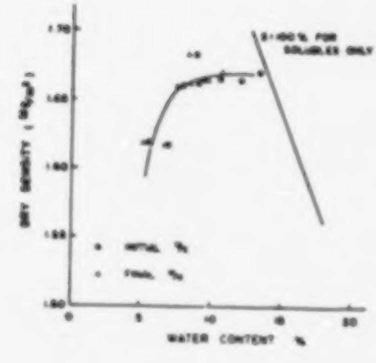


FIGURE 4.11: STANDARD PROCTOR TEST FOR CRUSHED MATERIAL AND 5% INSOLUBLES

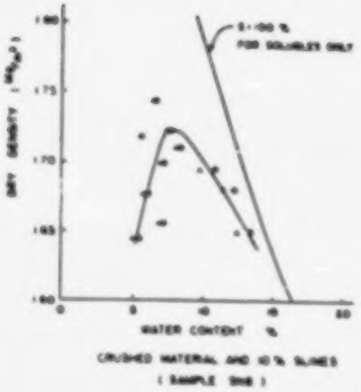


FIGURE 4.12: STANDARD PROCTOR TEST FOR CRUSHED MATERIAL AND 10% INSOLUBLES.

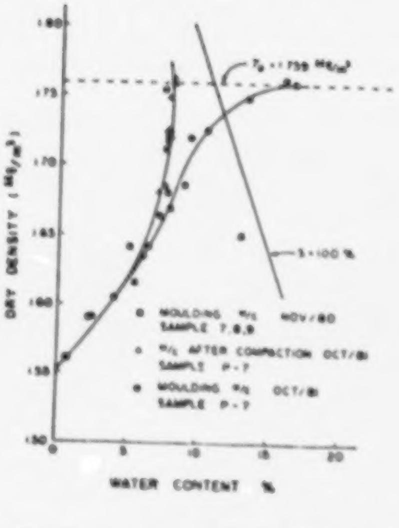


FIGURE 4.6: RESULTS OF MODIFIED PROCTOR TEST.

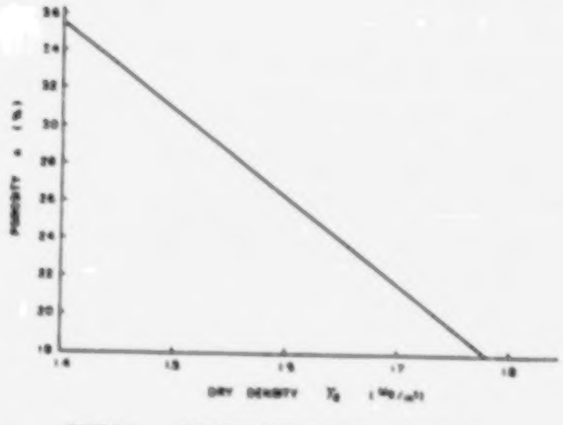


FIGURE 5.1: RELATIONSHIP BETWEEN DENSITY AND POROSITY.

Figure B-7.3

COMPACTION TESTS - SALT TAILS

From

UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yoshida,1982)

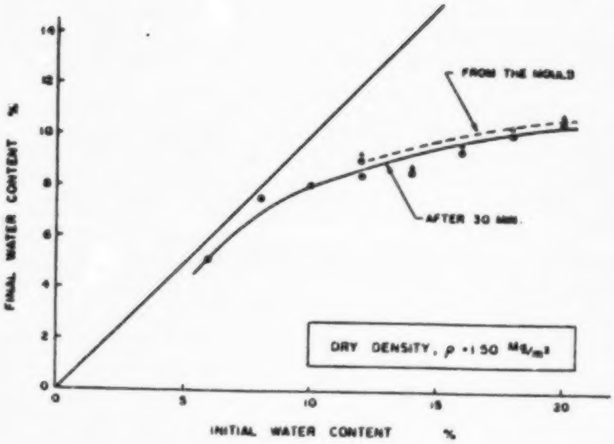


FIGURE 4.2: WATER HELD IN SPECIMEN AFTER COMPACTION, ρ_d = 1.50 Mg/m³.

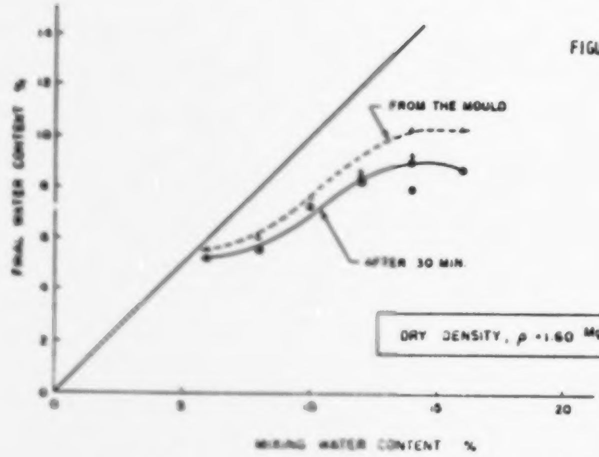


FIGURE 4.3: WATER HELD IN SPECIMEN AFTER COMPACTION, ρ_d = 1.60 Mg/m³

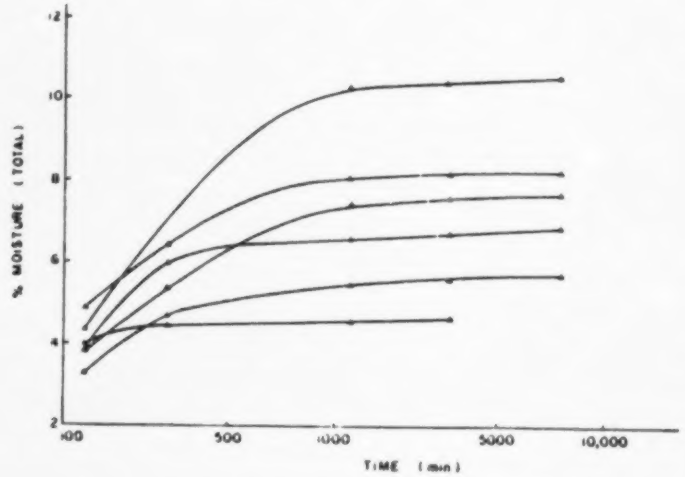


FIGURE 4.1: DRYING CURVE FOR POTASH TAILINGS

Figure B-7.4

WATER CONTENT RELATIONSHIPS-SALT TAILS
From
UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES
OF SALT TAILS (Pufahl and Yosheda,1982)

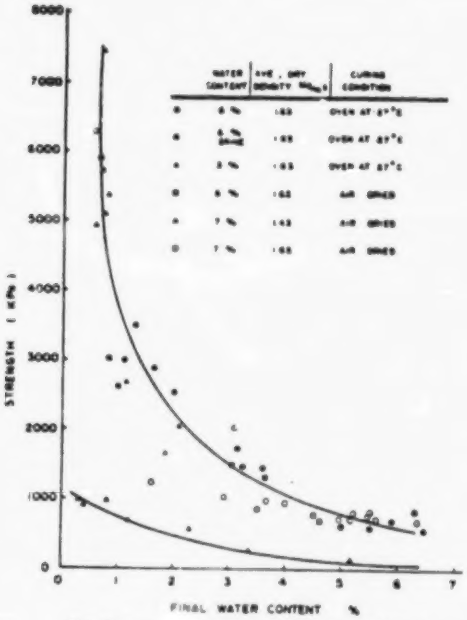


FIGURE 4.15: UNCONFINED COMPRESSIVE STRENGTH OF COMPACTED TAILINGS.

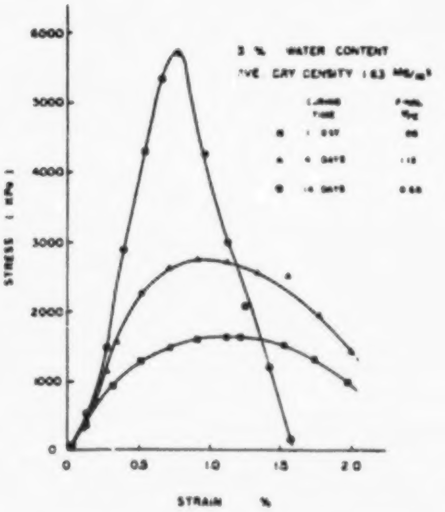


FIGURE 4.16: UNCONFINED COMPRESSIVE STRENGTH-STRESS - STRAIN RELATIONSHIP

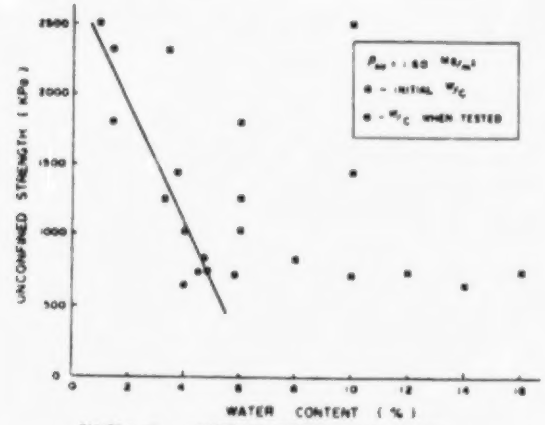


FIGURE 4.17: UNCONFINED COMPRESSIVE STRENGTH FOR TAILINGS COMPACTED WITH VARYING WATER CONTENTS.

Figure B-7.5

UNCONFINED COMPRESSIVE STRENGTH-SALT TAILS

From

UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yosheda,1982)

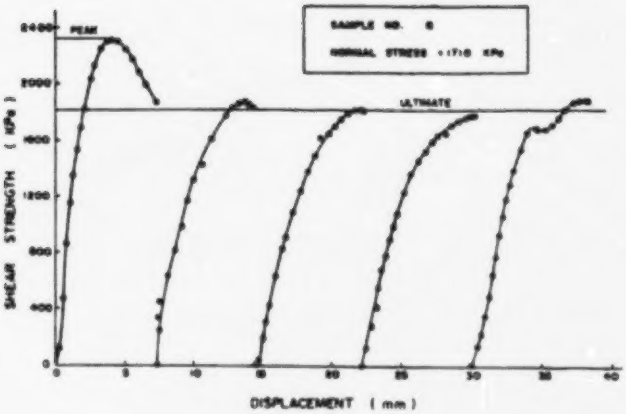


FIGURE 4.13: STRESS-DISPLACEMENT PLOT FOR DIRECT SHEAR TEST.

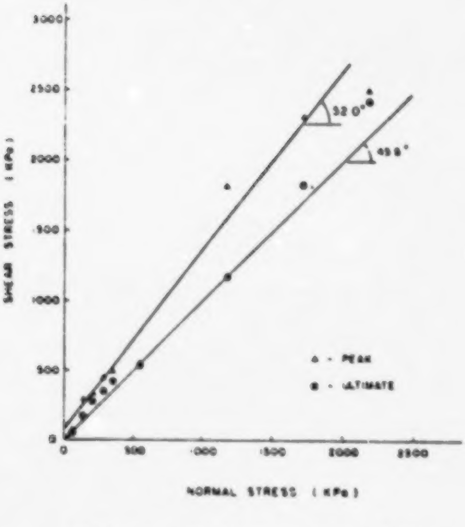


FIGURE 4.14: MOHR-COULOMB FAILURE ENVELOPE FOR DIRECT SHEAR TEST.

Figure B-7.6

DIRECT SHEAR TEST RESULTS-SALT TAILS
From
UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yoshoda,1982)

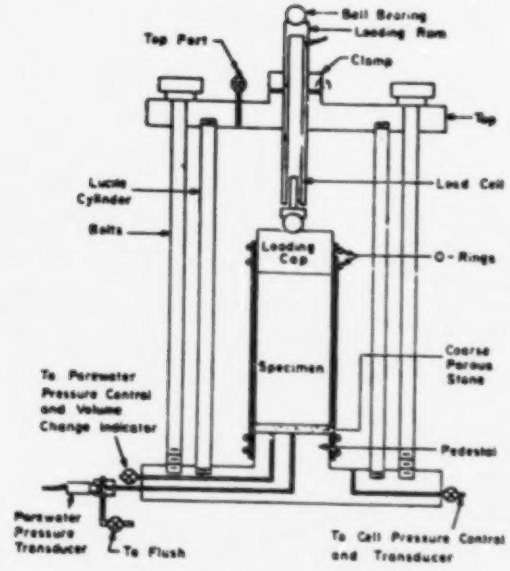

Ball Bearing
Loading Ram
Top Port
Clamp
Top
Lucite Cylinder
Load Cell
Bolts
Loading Cap
O-Rings
Specimen
Coarse Porous Stone
To Porewater Pressure Control and Volume Change Indicator
Pedestal
Porewater Pressure Transducer
To Flush
To Cell Pressure Control and Transducer

FIGURE 3.2: TRIAXIAL CELL.

TABLE 4.4

TRIAXIAL TEST RESULTS

Specimen	ρ_d Mg/m^3	w_o %	w_f %	σ_3 kPa	σ_1 kPa
T6-1	1.63	6.3	-	586	7036
53*	1.62	6.0	3.5	345	4453
T6-3	1.63	6.0	2.5	827	8428

* Oven dried @ 100°C

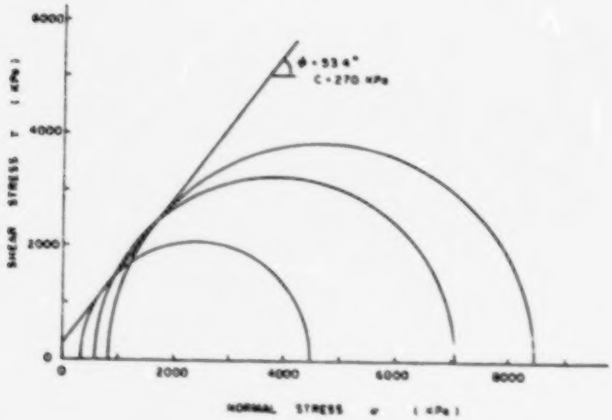


FIGURE 4.29: MOHR-COULOMB FAILURE ENVELOPE FOR TRIAXIAL TEST.

Figure B-7.7

CONSOLIDATED DRAINED TRIAXIAL TEST RESULTS-SALT TAILS
From
UNIVERSITY OF SASKATCHEWAN STUDY OF PROPERTIES OF SALT TAILS (Pufahl and Yosheda,1982)

B-7.2 University of Saskatchewan - Study of Elastic Parameters of Potash Tailings - PCS Mining Rocanville Division -(Pufahl and Loi, 1984)

In 1983, the University of Saskatchewan Geotechnical Group, under contract to PCS Mining, conducted a laboratory study of the elastic parameters of salt tailings. An attempt was made to predict Young's Modulus and Poisson's Ratio using the consolidated drained triaxial test. Samples were obtained from PCS Mining Rocanville Division. Samples were formed at different densities and tested under a range of effective confining pressures in the laboratory.

Strength data obtained from the triaxial tests may be summarized as follows:

Initial Dry Density	Effective Angle of Internal Friction	Effective Cohesion
1.60 Mg/m^3	48°	460 kPa
1.67 Mg/m^3	55°	100 kPa

To determine Poisson's ratio from the triaxial test the researchers made the assumption that lateral deformation is uniformly distributed over the sides of the sample. By measuring volume change and vertical strain the above assumption was used to calculate Poisson's Ratio.

The computation of deformation moduli (E) was done by fitting a straight line through the initial state of stress vs. strain curve plot.

When the samples were tested in triaxial compression an initial decrease in volume was followed by rapid dilation at failure.

The study concluded that Young's Modulus and Poisson's ratio are both functions of initial density. For densities ranging from 1.5 Mg/m^3 to 1.7 Mg/m^3 and confining pressures ranging from 400 kPa to 900 kPa, the studies suggest a range as follows:

Poisson's Ratio: 0.4 to 0.5

E Modulus: 250 to 800 MPa

B-7.3 Golder Associates (1977), Geotechnical Recommendations Concerning Tailings Pile Stability

Under contract to PCS Mining in (1977), Golder Associates conducted a site investigation and tails pile stability studies at the PCS Mining Cory Division minesite. In conjunction with the stability studies a number of tests were conducted on both the tails slurry and on samples recovered from the tails pile.

B-7.3.1 Laboratory Permeability Tests

Samples of the tails-slimes-brine slurry were obtained from the tails discharge line. Samples were reconstituted in the laboratory to what was considered a typical fine gradation and a typical coarse gradation.

Values of e_{max} and e_{min} were determined in the laboratory as follows:

	Fine Gradation	Coarse Gradation
e_{max}	0.86	0.81
e_{min}	0.37	0.40

Constant brine pressure head tests were then conducted for void ratios from approx. 0.40 to 0.75.

B-7.3.2 Direct Shear Tests

Block samples recovered from the tails pile were tested in the laboratory direct shear apparatus. Six direct shear tests were conducted using 60 mm square by 25 mm thick samples. These tests indicated an effective angle of internal friction somewhere in the range of Ø' = 45° to 0' = 60°. A second series of tests was conducted on samples 130 mm by 75 mm by 50 mm thick. For these samples Golder Associates suggested a curved failure envelope with Ø' decreasing as the effective normal stress was increased. This non-linear function was thought to possibly be a result of particle degradation under high stresses.

B-7-3.3 Field Permeability Tests

A series of falling head permeability tests estimated the permeability of the insitu tailings to be in the order of 3 to 5 x 10^{-3} cm/sec.

B-7.3.4 Field Observations

During the field investigation Golder Associates noted that the tailing pile typically contained slimes layers composed of silt and clay sizes up to 50 mm thick with one layer noted to be 1 200 mm thick. The degree of cementing of the tailings was noted to be variable.

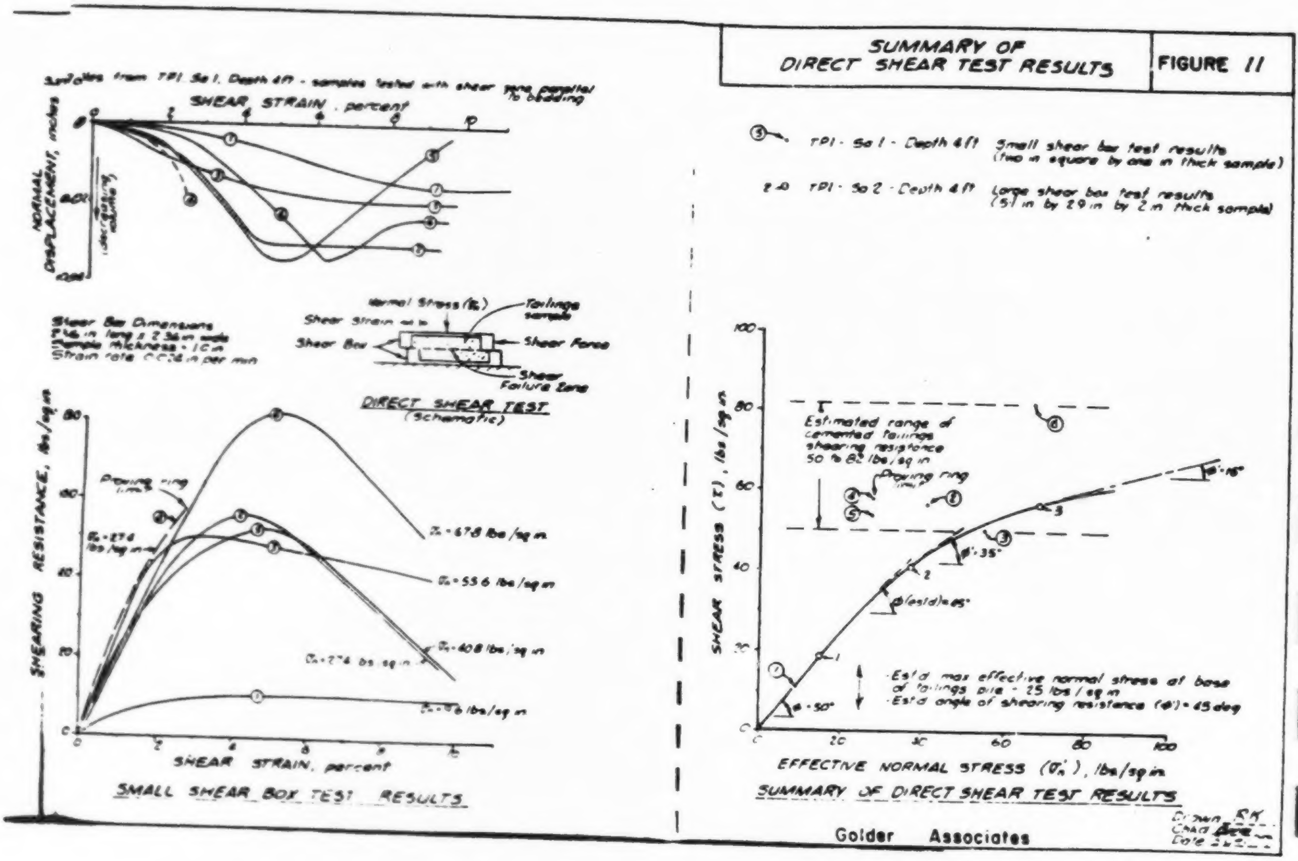


Figure B-7.8

DIRECT SHEAR TEST RESULTS - SALT TAILS

PCS MINING LANIGAN DIVISION

From

GOLDER ASSOCIATES (1977)

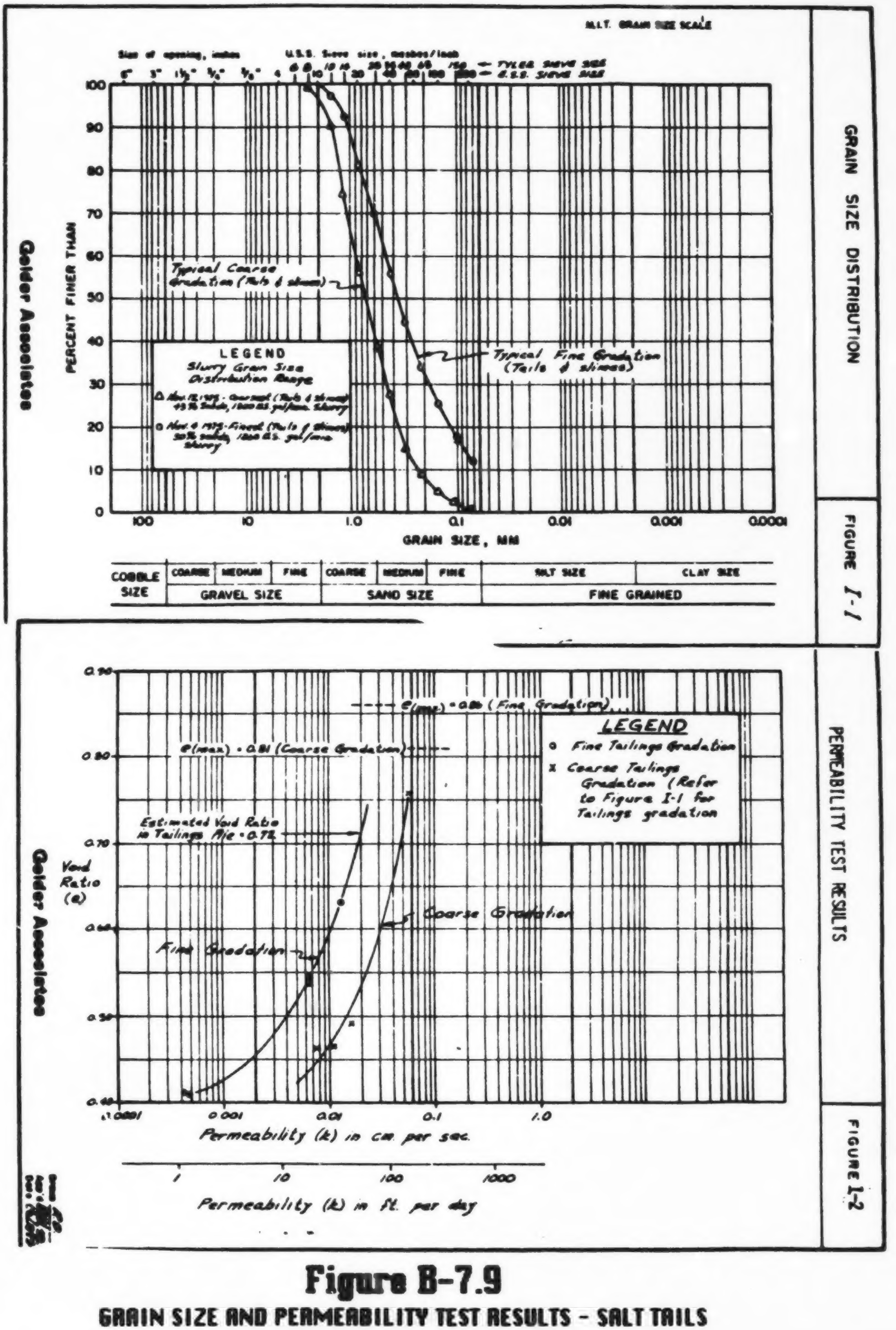


Figure B-7.9

GRAIN SIZE AND PERMEABILITY TEST RESULTS - SALT TAILS
PCS MINING LANIGAN DIVISION
From
GOLDER ASSOCIATES (1977)

B-7.4 Golder Associates (1983), Field Investigation Program - Salt Tails, PCS Mining Lanigan Division

Golder Associates were retained by PCS Mining to conduct a field investigation of the tailings facility at the PCS Mining, Lanigan Division minesite.

Numerous samples were recovered from the tails pile. Techniques included block sampling, diamond coring and driving split spoons. Piezometers, inclinometers and thermisters were installed in and below the tails pile. Additional testing included downhole geophysical logging an pressuremeter testing.

The investigation indicated a high degree of stratification and lamination within the salt tails.

Samples recovered are currently being tested by the University of Saskatchewan Geotechnical Group.

APPENDIX C

PROJECT PROPOSAL

PCS
Mining
A subsidiary of the Potash Corporation of Saskatchewan

PCS
Mining
A subsidiary of the Potash Corporation of Saskatchewan

PART I Investigation of the Physical and Chemical Characteristics of Salt Tailings and Associated Slimes

Objectives:

The objectives of this investigation will be to determine the strength of potash tails and the influence of slimes on tailings strength through an investigation into the physical and chemical characteristics of potash tailings.

Background:

Millions of tonnes of potash tailings are produced in Saskatchewan each year resulting in large piles, each exceeding 100 ha in area and ranging from 30 to 60 meters in height. They are composed of NaCl and up to 10% insolubles (slimes) which are comprised of clays and sedimentary minerals. In order to insure the integrity of the surrounding dikes which contain millions of liters of brine, large scale failure of the tailings piles resulting in a breach of the dikes and serious environmental impact, must not occur. Unfortunately little is known about the likelihood of pile failure which could occur either through sub-soil displacement or due to an internal slip plane or excessive tailings height and slope angle which would exceed the tailings strength.

Due to the slimes component's small particle size and high clay content, it appears that slime content and possibly placement of slimes within the tailings pile determines the piles overall strength and resistance to failure. Little is known about the strength of slimes alone or its influence on the strength of salt tailings. The industry has some control over the extent of slimes-salt tailings mixing and, if necessary, has the option of separately storing the two wastes. In order to make the right waste management decision, an understanding of the influence of slimes on tailings strength when the slimes and tailings occur as a mixture and the strength of slimes when it is present as a layer or internal slip plane separating salt tailings is necessary.

If the likelihood of failure of a pile can be decreased by separating salt wastes and slimes, it will be necessary to determine the slimes strength alone so that slimes placement and pile configuration minimizes the chances of a slimes pile failure. Since slimes would be stored outside it would also be necessary to evaluate the change in slimes strength as the salts in the slimes pile are gradually leached away.

Methodology:

In order to account for slimes variability between mines and ore bodies, Cory and Rocanville which represent the extremes in the clay content of the slimes will be visited and sampled. Mineralogical analysis by the Saskatchewan Research Council will be conducted on these samples to ensure that they are representative and to relate slimes strength to mineralogical characteristics. To determine the influence of slimes on pile stability strength tests will be conducted by a local geotechnical lab on salt waste, slimes-salt waste mixtures and on slimes alone. In order to evaluate changes in competence as salts are leached from slimes as might occur in outside slimes storage, strength tests will be performed on both washed and unwashed samples.

The above information will be analyzed and discussed with the practical consideration of how slimes influence pile stability and what is the best solid-waste storage options available to the potash industry. The report will include all lab data and analyses.

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